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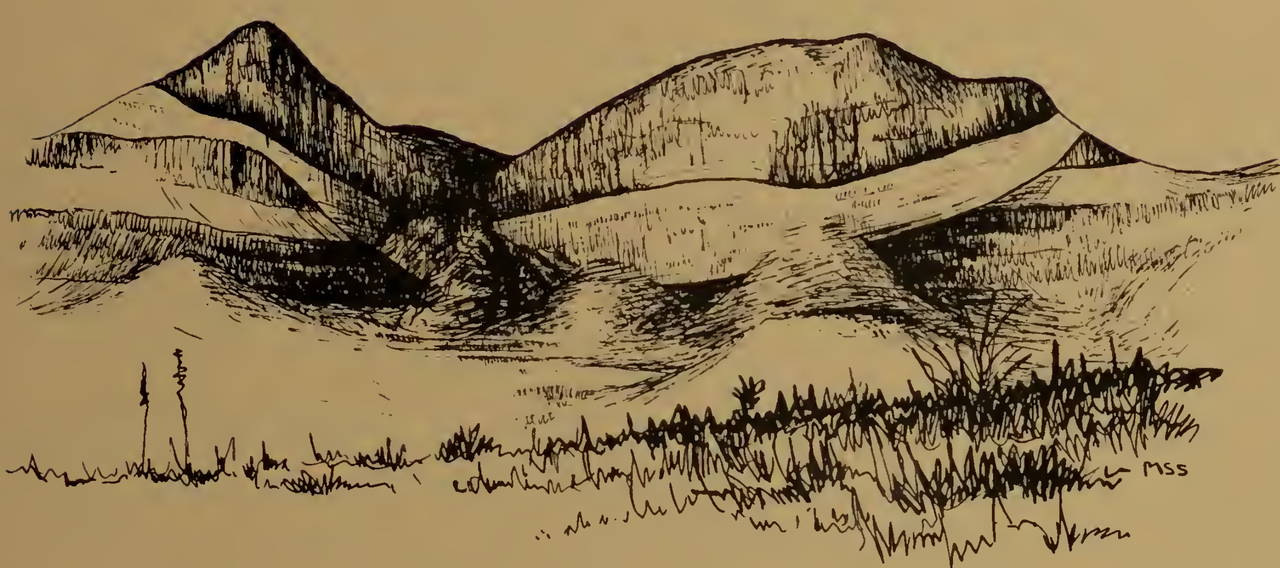
FIELD SEMINAR
of the
BIG BEND, TRANS-PECOS REGION
TEXAS



HOUSTON GEOLOGICAL SOCIETY
GUIDEBOOK
APRIL, 1986

FIELD SEMINAR
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BIG BEND, TRANS-PECOS
TEXAS

James B. Stevens - Leader

David C. Roberts - Coordinator

Margaret S. Stevens - Illustrator

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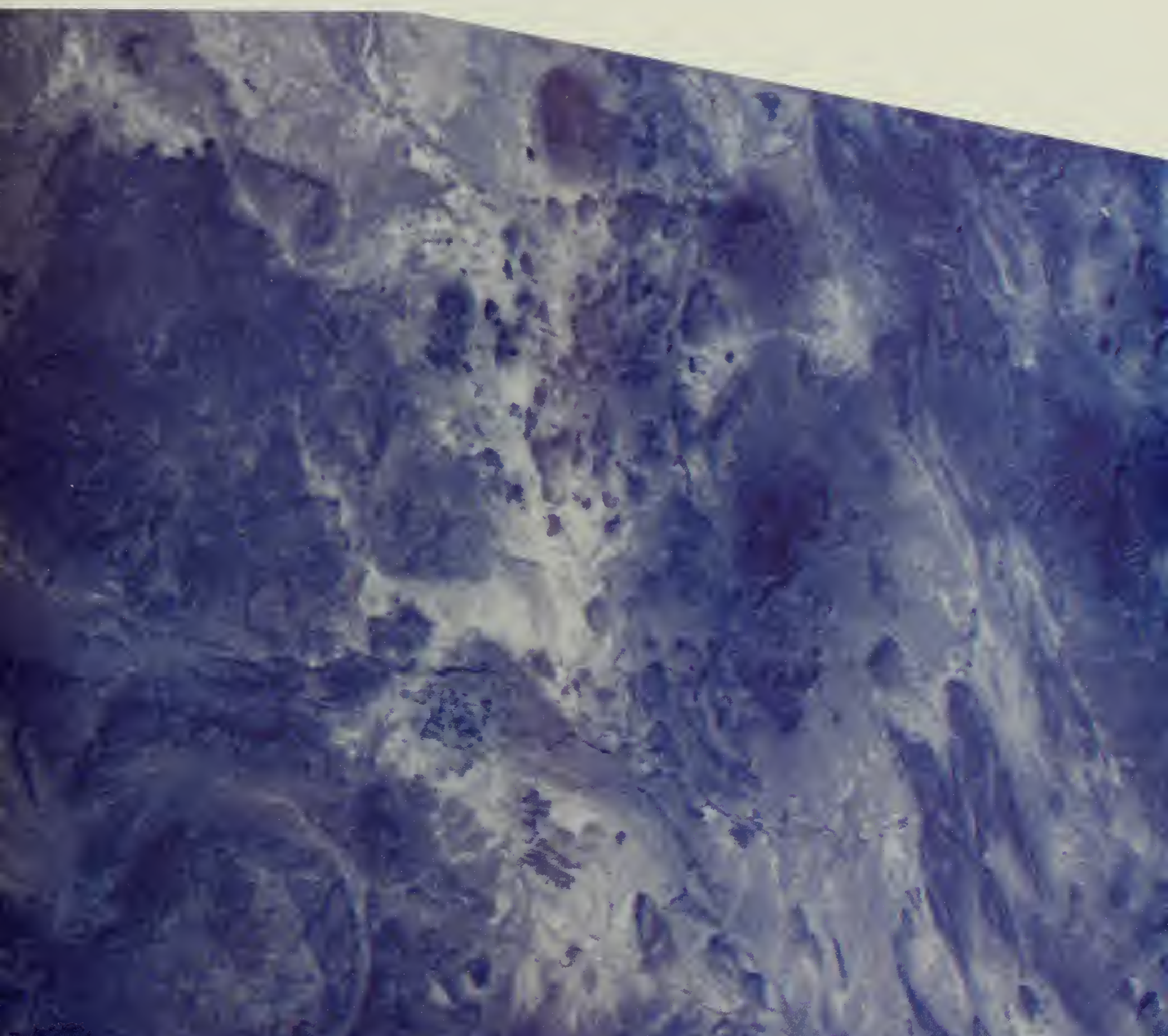

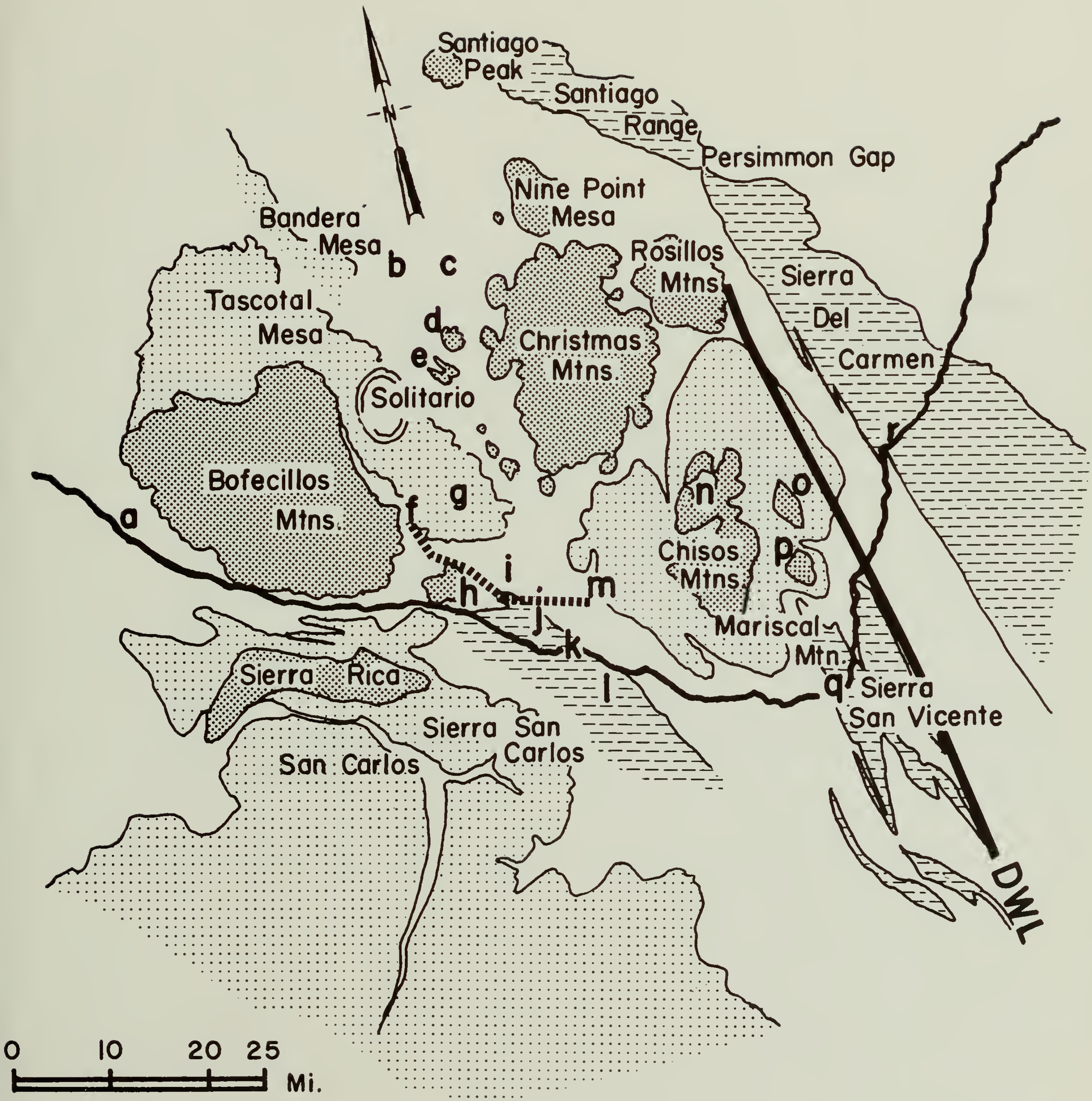

Santiago Peak
Santiago Range
Persimmon Gap
N
Nine Point Mesa
Bandera Mesa
b
c
Rosillos Mtns
Sierra Del Carmen
Tascotal Mesa
d
e
Christmas Mtns
Solitario
Bofecillos Mtns.
a
f
g
n
o
p
Chisos Mtns.
i
h
m
j
k
Mariscal Mtn.
r
Sierra Rica
l
q
Sierra San Vicente
Sierra San Carlos
San Carlos
DWL
0 10 20 25
Mi.

FRONTISPIECE--(Plate 1b). Map locations of some physiographic elements shown in Plate 1A, and explanation for lettered symbols.

a--Redford

b--Devil's Graveyard

c--Fizzle Flat

d--Aqua Fria Mtn.

e--Black Ridges

f--Fresno Canyon

g--Black Mesa

h--Lajitas

i--The Reed Plateau, approximately

j--Mesa de Anguila

k--Santa Elena Canyon

l--Sierra Ponce

m--Terlingua Monocline, checkered tape strip

n--The Basin

o--Chilicotal Mtn.

p--Talley Mtn.

q--Mariscal Canyon

r--Boquillas Canyon

DWL - Dugout Wells Lineament

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Letter of Acknowledgement

The HGS Field Trip Committee would like to give their sincere appreciation and thanks to the people, institutions and organizations who gave generously of their time and support to make this project successful.

We wish to thank the HGS Executive Committee (1985-86) for sponsering the Fieldguide and field trip. Thanks to the Department of Geology, Lamar University, Beaumonth, Texas and to their Department Head, D.E. Owen and assistants for helping to prepare this Fieldguide.

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Our appreciation and thanks go to Margaret S. Stevens for preparing and donating her beautiful illustrations used in the Fieldguide. Thanks to Pat Dickerson, Conoco, Midland, Texas, for researching the Landsat image and to Dave Amsburg, NASA, Houston, for contributing the Frontispiece. We wish to thank the contributing authors for their papers which are a crucial part of this project.

Thanks to our typists; Terry Ann Bautz, Charla Bradford, Sandra Triolo and Stephanie L. Young for work well done in a timely fashion. We appreciate the support of Schlumberger Well Services for contributing refreshments to the field trip and to all advisors.

We realise that the work of many scientists, throughout the years has built the foundation of knowledge we base this Fieldguide on. To them our sincere thanks. We did not mean to forget anyone, but if we did, thank you very much for helping make this project a success.

See you at the outcrop

David C. Roberts, Coordinator
James B. Stevens, Leader

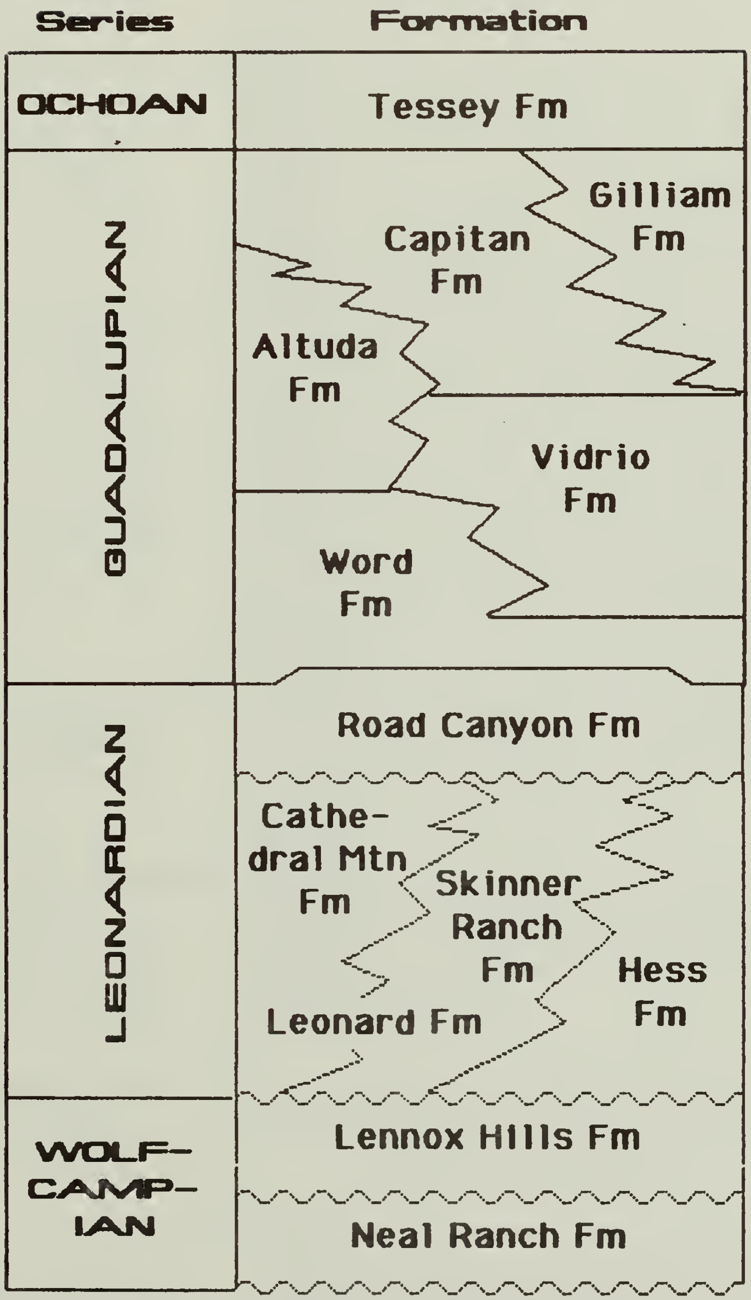
Correlation Chart for the Marathon Basin and the Ouachita Mountains

(After King, 1977)

System / Series	Marathon Region	Ouachita Mountains
Virgillian, Missourian, DesMoinesian	Gaptank Fm	Hartshorne Ss, & equivalents
Atokan	Haymond Fm	Atoka Fm
Morrowan	Dimple Ls	Johns Valley Fm Wapanucka Ls
Chesterian Meramecian	Tesnus Fm	Jackfork Ss Stanley Shale
Osageian	Presence doubtful	
Kinderhookian Devonian	Caballos Novaculite	Arkansas Novaculite
Silurian	Hiatus	Missouri Mtn Shale Blaylock Ss
Upper Ordovician	Maravillas Chert	Polk Ck Shale Bigfork Chert
Middle Ordovician	Woods Hollow Shale Fort Peña Fm	Womble Shale Blakely Ss
Lower Ordovician	Alsate Shale Marathon Ls	Mazarn Shale Crystal Mtn Ss Collier Shale
Upper Cambrian	Dagger Flat Ss	Not Exposed

CHART 1

Permian System
Glass Mts
Trans-Pecos Texas



Modified from stratigraphic nomenclature used by Dickerson and Muehlberger (1985), and Ross and Ross (1985).

CHART 2

Comanchean Series, Big Bend Region, Texas

STAGE	GROUP*	FM NAME, THICKNESS, LITHOLOGY	COMMENTS
Cenomanian	Washita	**Buda Fm** 40 - 100 ft (12 - 31 m)	The name BUDA is used very widely in Texas; in the Big Bend region, this very pale limestone with characteristic conchoidal fracture usually has three distinctive subunits, each with a marly thin-bedded base. The disconformity at the base is not impressive, but paleontological evidence suggests erosion or by-passing.
Cenomanian	Washita	(?) **Del Rio Fm** 5 - 110 ft (1.5 - 34 m)	This brown fm often has slopes covered by orange rubble of weathered thin layers of siliceous limestone and sandstone interbedded with dominant shale. It correlates with the GRAYSON Fm (NE Texas), and the EAGLE MTNS Fm to the NW. It was named by Hill and Vaughan (1898).
Cenomanian	Washita	**Santa Elena Fm** 740 - 850 ft (226 - 259 m)	Correlates with the GEORGETOWN Fm, above the DUCK CREEK Mbr (Maxwell et al, 1967), and with at least the SAN MARTINE Mbr of the BORACHO Fm (N); and the ESPY Fm (NW). A ledgy weathering profile marks the upper 100 ft of SANTA ELENA from E of Langtry to the Big Bend region, where it was named (Maxwell et al, 1967).
Albian	Fredericksburg	**Sue Peaks Fm** 250 (ave) - 275 ft (76 - 84 m)	Maxwell et al (1967) named this unit and correlated it with the KIAMICHI Fm of Central Texas, and, at the top, with the DUCK CREEK Mbr of the GEORGETOWN Fm. This kind of situation makes comparison with groups established in Central Texas difficult.
Albian	Fredericksburg	**Del Carmen Fm** 350 - 465 ft (107 - 142 m)	Maxwell et al (1967) named this fm and correlated it with the EDWARDS Fm (Central Texas), and the FINLAY Fm to the N and W; UTBEG usage correlates it with the FT TERRETT and the lower part of the SEGOVIA mbrs, EDWARDS Fm in S Texas.
Albian	Fredericksburg	**Telephone Canyon Fm** 75(Ave) - 145 Ft (23 - 81 M)	Named by Maxwell et al (1967), this unit correlates with the WALNUT Fm (in part), and to the lower part of the COMANCHE PEAK Fm; to the NW, it may correlate with the upper part of the COX Fm and the lower part of the FINLAY Fm.
Albian	Trinity	**Maxon Fm** 10 - 40 Ft (3 - 12 M)	Channel ss., shale and marl roughly equivalent with the PALUXY Fm to the E and to part of the COX (?) Fm to the NW; it is present to the E but not known in the Park. This unit was named by P. B. King (1937).
Albian	Trinity	**Glen Rose Fm** ca 500 - 550 ft (152 - 168 m)	The red basal shales, conglomerates, and sandstones are persistent to the N and W, and are equivalent to, and may originally have been continuous with, the YEARWOOD, and BISSETT fms, and thus be correlative in part with the YUCCA Fm. The limestone thins to the N; it correlates with the BLUFF Fm, and the KIAMICHI Fm of some usages.

* Boundaries approximated, for purposes of comparison

UTBEG - The University of Texas, Bureau of Economic Geology

Consultation of the appropriate COSUNA chart (Hills and Kottlowski, 1983) makes it clear that there are problems of correlation in the Comanche Series of this area that will not be solved on this trip.

CHART 3

Gulfian Series, Big Bend Region, Texas

STAGE	GROUP	FM NAME, THICKNESS, LITHOLOGY	COMMENTS
Maas-strich-tian	Tornillo	**Javelina Fm** 240 - 930 ft (73 - 284 m)	The TORNILLO Gp, and the JAVELINA Fm, named by Maxwell et al (1967) are, upward, increasingly dominated by colorful smectitic clays. The JAVELINA correlates with the KEMP and ESCONDIDO fms. Deposition appears to be discontinuous at the top, and the K - T boundary is not preserved (?), but there are many saurian fossils.
Cam-panian	Tornillo	**Aguja Fm** 763 - 1171 ft (232.5 - 356.9 m)	The AGUJA Fm (Adkins, 1933) has a variable thickness, which, as with the underlying fm, may result from difficulty in defining the contacts. This deltaic and littoral fm may correlate with the PECAN GAP, and ANACACHO fms.
Santonian (?)	Terlingua	(?) **Pen Fm** 219 - ca 700 ft (67 - 213 m)	The PEN Fm named and added to a redefined TERLINGUA Gp by Maxwell et al (1967), is a grey shale weathering to yellow, increasingly limey toward its base which is lithologically indistinct. The PEN Fm may correlate with the upper part of the AUSTIN Gp (DESSAU Fm, and higher) in UTBEG usage.
Santonian (?)	Terlingua — Boquillas Fm	(?) **San Vicente Mbr** 130 - 400 ft (40 - 122 m)	This unit was named by Udden (1907), but redefined by Maxwell et al (1967) who named the two members; the upper mbr was correlated with the AUSTIN CHALK Fm, but in modern terms may correlate with the AUSTIN Fm, AUSTIN Gp. The Inoceramus undulatoplicatus (giant oyster) Zone is a highly characteristic feature near the top. The disconformity between the two members is not striking, but the thicker bedding of the lower mbr, and lesser interlayered marly shales make the two units mappable. The lower mbr probably corelates with the EAGLE FORD Fm; both units may correlate with the OJINAGA Fm.
Conia-cian	Terlingua — Boquillas Fm	**Ernst Mbr** 450 ft (137 m)	

UTBEG - The University of Texas, Bureau of Economic Geology

CHART 4

Lower Tertiary Series, Big Bend National Park

STAGE*	GROUP	FM NAME**, THICKNESS, LITHOLOGY			COMMENTS
Lower Oligocene	Big Bend Park	**South Rim Fm** ca 275 - 1000 ft (84 - 305 m)		Compl. Volc. Liths. ***	This magmatically unified set of rocks records cyclic development of the Pine Canyon Caldera (NE Chisos Mts) (Ogley, 1979), and appears to be related to the younger CHISOS MTS PLUTON. It is roughly correlative with the FRESNO and TASCOTAL fms in and N of the Bofecillos Mts. Eruptions that escaped the caldera flowed to the S and W.
? Uintan	Big Bend Park	**Chisos Fm** 1435 - 3438 ft (437 - 1048 m)		Compl. Volc. & Sed. Liths. ***	The diverse CHISOS Fm contains mafic and silicic lavas, and volcanic apron sedimentary rocks. Sources are unknown, but at least three lava mbrs can be traced NW into the Bofecillos Mts. It correlates with the mid and upper parts of the DEVIL'S GRAVEYARD Fm (NW) and the DECIE and PRUETT fms (Alpine and Southern Davis Mts areas).
Uintan	Big Bend Park	Canoe Fm	**unamed Upper mbr** 611 - 1129 ft (186 - 344 m)		Most recently studied by Rigsby (1982, 1986), the UPPER mbr, CANOE Fm, is probably a part of the constructive volcanic apron associated with the CHISOS Fm, and consists of zeolitized fluvial volcaniclastic sediments
Bridgerian	Big Bend Park	Canoe Fm	**Big Yellow Mbr** ca 30 - 50 ft (9 - 15 m)		Rigsby considered this a deposit of a major, mainly transportational braided river, ancestral to the Rio Conchos - Rio Grande system. It probably correlates with similar deposits near the base of the DEVIL'S GRAVEYARD Fm, and perhaps to some basal CHISOS fm near Lajitas. The base of the CHISOS Fm there is older than it is in the Park.
Wasatchian	Tornillo	**Hannold Hill Fm** 144 - 833 ft (44 - 254 m)			The HANNOLD HILL Fm contains one minor named mbr, the EXHIBIT Mbr, a conglomeratic sandstone; and, according to Maxwell et al (1967), the only Tertiary lignite deposit in the area. In general, it consists of colorfully banded mudstone and clay, and minor fine sandstone lenses.
Torrejonian, Tiffanian, and Clarkforkian	Tornillo	**Black Peaks Fm** 315 - 866 ft (96 - 264 m)			Schiebout (1974) described this colorful unit as deposits of small meandering rivers in a tropical - semi-tropical climate. Wilson's vertebrate biostratigraphy (in Maxwell et al, 1967) lead to the separation of this and the lithologically similar HANNOLD HILL and JAVELINA fms ▼

* Inasmuch as the ages of most of these units were established by vertebrate biostratigraphy (Wilson, in Maxwell et al, 1967; and many other publications, notably, 1980), it seems appropriate to use the North American Land Mammal Stages, where possible. Berggren et al (1985) give the following equivalencies: Torrejonian, Tiffanian, and Clarkforkian would include rocks of later Early Paleocene through older Early Eocen age. In the Park, it is believed that the oldest Tertiary rocks are about mid Paleocene in age. Wasatchian would refer to rocks of approximately Early to oldest Middle Eocene age; Uintan rocks would be later Middle to older Late Eocene in age.

** All lithostratigraphic units were named in Maxwell et al (1967).

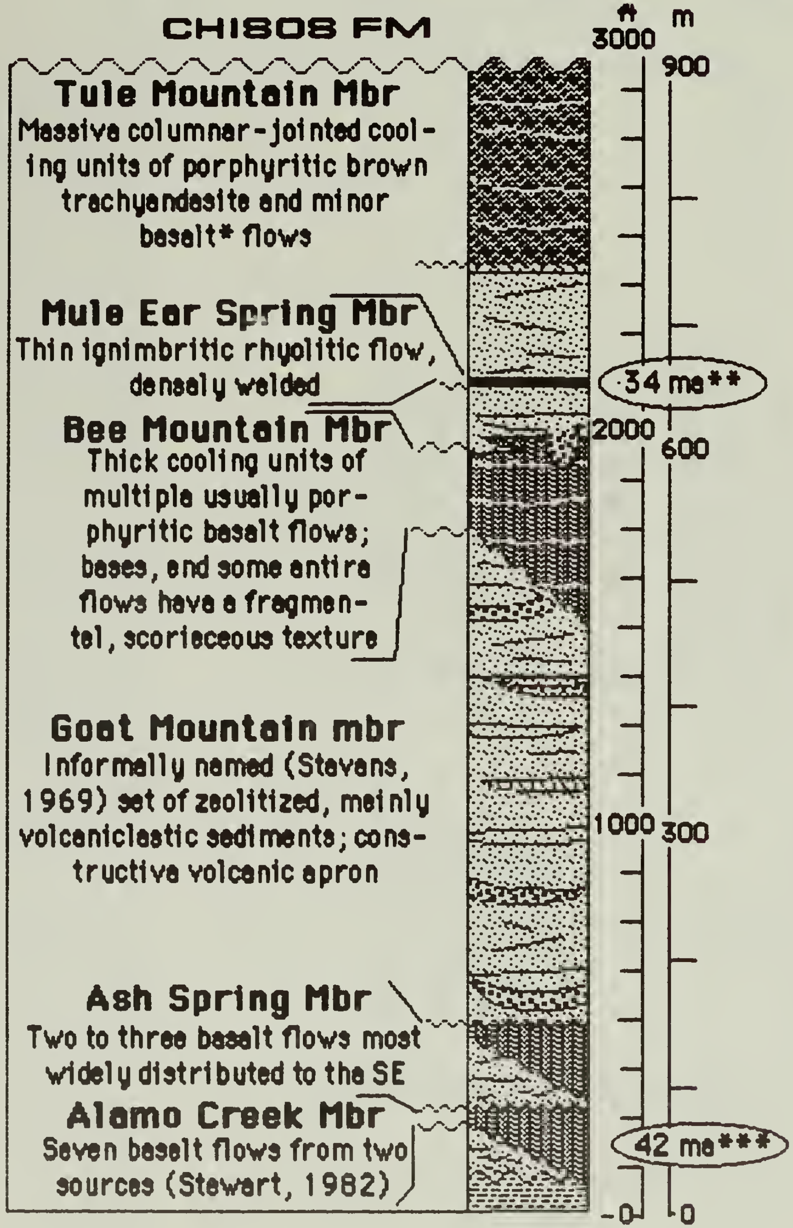
*** For details of the stratigraphy of the Chisos and SOUTH RIM fms see the following page.

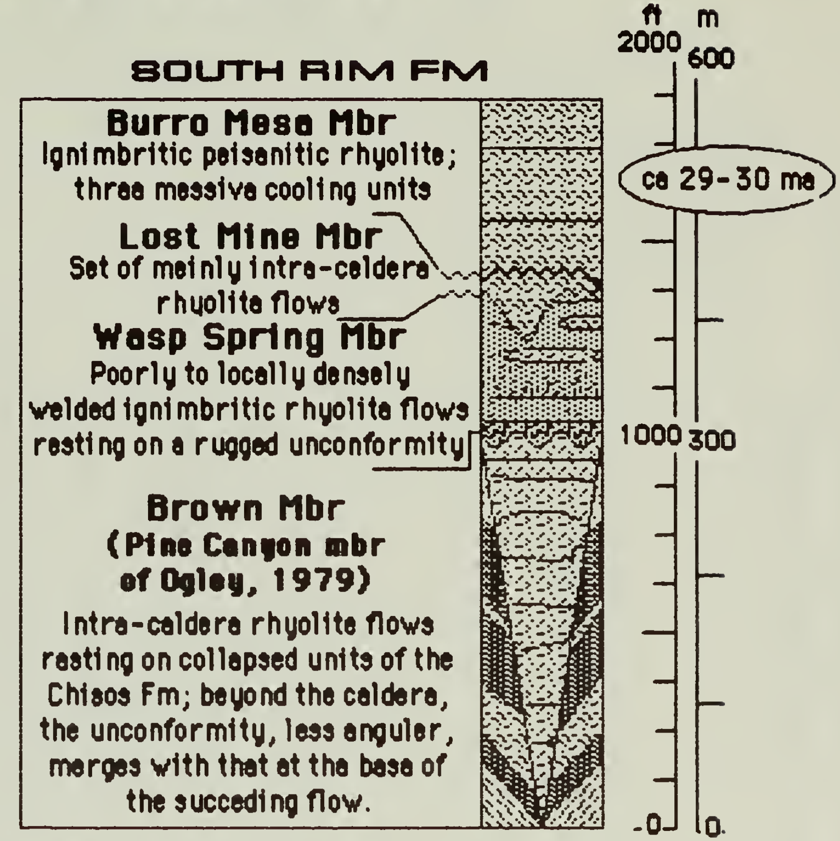
▼ Thickness of these units is in some doubt, because the lithologic similarity, and apparently gradational contacts, despite significant differences in age, make detailed determination of stratigraphic position difficult.

CHART 5

Details and Schematic Representation of the Chisos and South Rim formations

(All information, except as noted, derived from Maxwell et al, 1967)





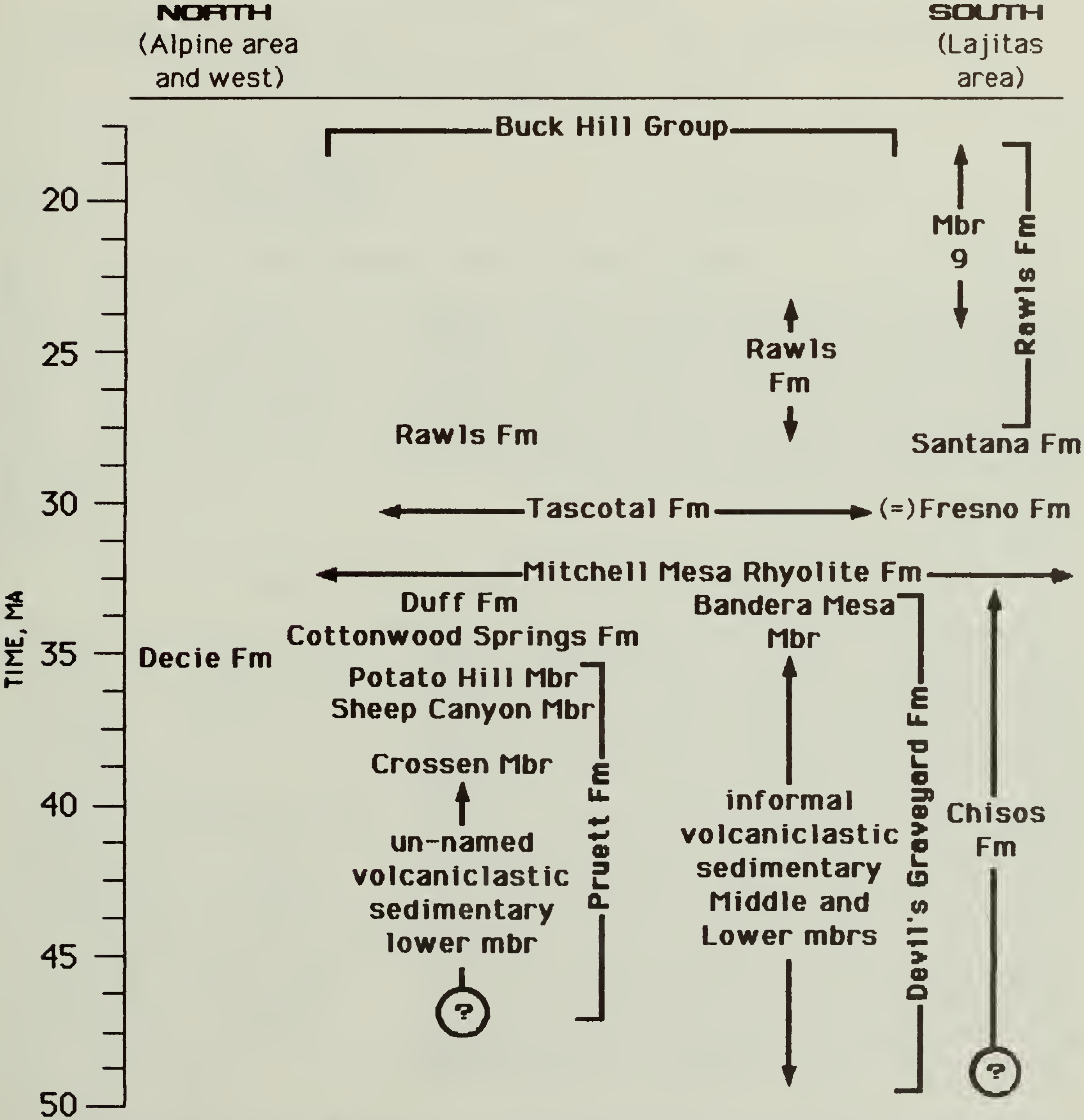
* The term "basalt" is used here as a field term for very dark grey volcanic rock. True basalt is rare in Trans-Pecos Texas; most "basalt" is mugearite or hawaiite (Barker, 1977, and personal conversations).

** The date for the Mule Ear Spring Member was supplied by C. D. Henry (personal communication, 1985).

*** The date for the Alamo Creek Member is an approximate average of many dates obtained by a number of workers. See McDowell (1979), and Stevens and Stevens (1985) for discussion.

CHART 6

Tertiary Stratigraphy North of Big Bend National Park



Sources: Decie Fm: Parker and McDowell (1979), Parker (1979, 1983); Buck Hill Group: Goldich and Seward (1948), Goldich and Elms (1949), Erickson (1953), Moon (1953), McAnulty (1955), Wilson (1972, 1974, 1977), Stevens (1979), Stevens et al (1984); Lajitas (Bofecillos Mts) area: Dietrich (1966), McKnight (1970), Maxwell and Dietrich (1970), Clark and Gilliland (1978), Walton (1978), Gilliland and Clark (1979), Stevens, M. S., and Stevens, 1983.

CHART 7

Series of the middle and later Tertiary, and Quaternary, Big Bend Region, Texas

	FM NAME, THICKNESS, LITHOLOGY	COMMENTS
	Northeast side, Chisos Block	
Pleisto-cene (?) / Plio-cene (?) / U. Mio cene	**Estufa Canyon fm** * 1452 - ca 1682 ft (443 - 513 m)	The unit rests with angular unconformity on various lower Tertiary and upper Cretaceous fms. Coarse conglomerate of the upper 2/3 of the unit is corelated with the FINGERS fm (Sotol Vista) but the unit as a whole has no other known correlative units in Trans-Pecos Texas. It represents three episodes of alluvial fan building, of which the oldest is ca 9 ma; angularity between successive deposits is minimal.
	Southwest Side, Chisos Block	
Pleisto-cene (?)	**Fingers fm** * ca 60 - 682 ft (18 - 208 m)	This proximal fan deposit known from the Sotol Vista - Burro Mesa area has no known correlatives except as noted above. It and the upper part of the ESTUFA CANYON fm record late stages of partial burial of the Chisos Mts. Pedimentation of this unit accompanied excavation produced by the establishment of the modern Rio Grande drainage.
M. Mio-cene (?)	Delaho Fm: **Smoky Creek Mbr** > 1090 ft (332 m)	This second suite of alluvial fan deposits correlates with parts of Mbr 9, RAWLS Fm (ca 18 ma), and possibly with the TARANTULA Fm of the Tierra Vieja, to the NW. This may be the oldest unit clearly attributable to Basin and Range tectonism in Trans-Pecos Texas.
L. Mio-cene	Delaho Fm: **Lower mbr** * ca 1100 ft (335 m)	The LOWER mbr, DELAHO Fm is correlative with lowest parts of MBR 9, RAWLS Fm, and with some un-named bodies of sediment in Trans-Pecos Texas. There is a near-basal basalt flow dated at 23 ma., and an abundance of vertebrate fosils. As a whole, this unit, even its proximal facies, is much finer than younger alluvial fan deposits.

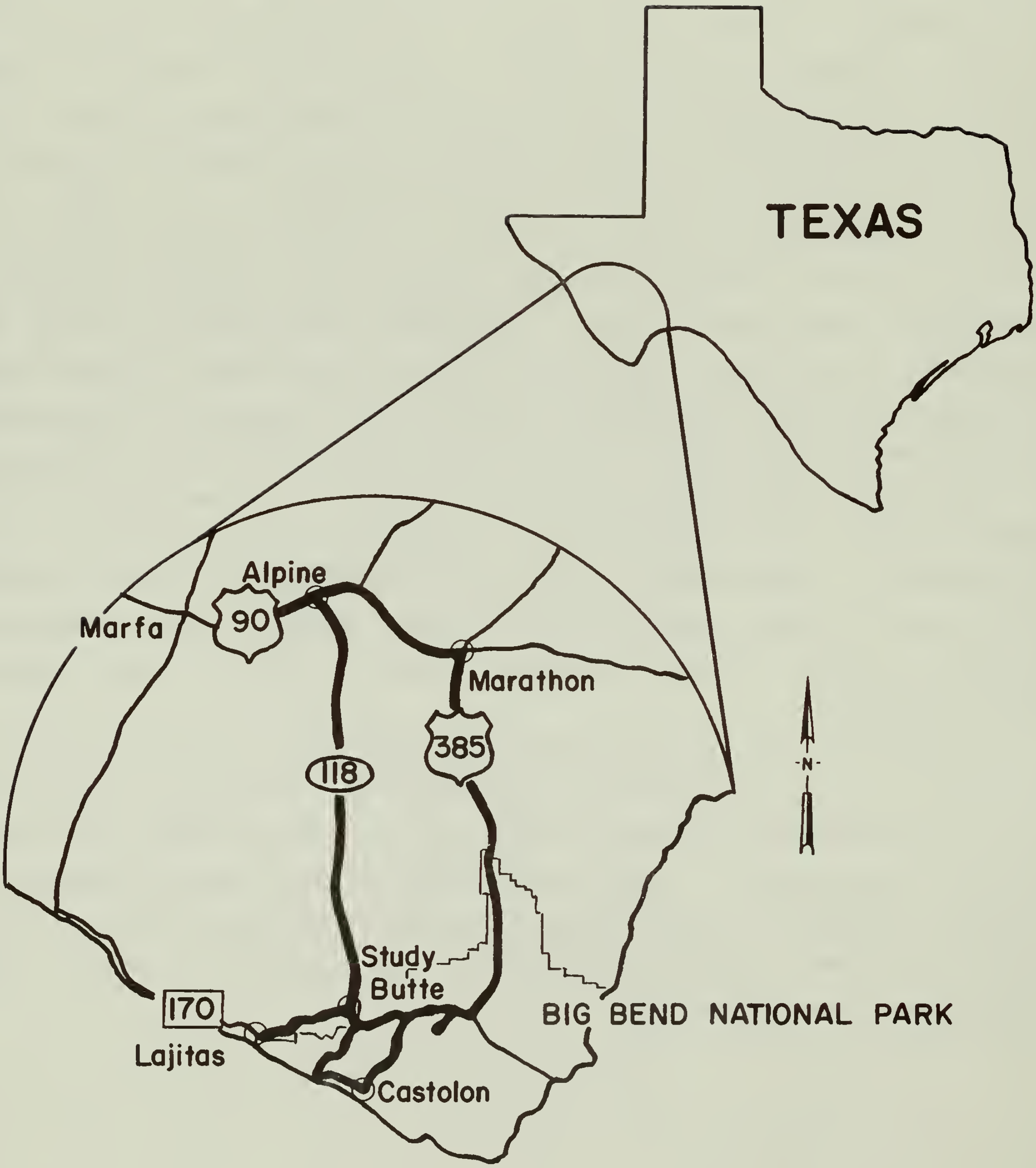
* Informally named lithostratigraphic units; the ESTUFA CANYON Fm is currently being investigated by M. S. Stevens (vertebrate biostratigraphy) and J. B. Stevens (physical stratigraphy). The results of this study will probably affect the status of the FINGERS fm. All names have been approved by the Geologic Names Committee, United States Geological Survey.

CHART 8

INTRODUCTION TO DAILY ROAD LOGS

Although most of the area traversed during this field trip (see Fig. 1) is familiar ground for me, it is important to note that without the basis provided by other workers, it would be much less so. For the Terlingua Mining District, Yates and Thompson (1960) provide an extraordinary quality of basic information. Any discussant of geology in the Big Bend region is bound to use the citation "Maxwell et al (1967)" with what may seem excessive regularity; but despite pioneering work, some of it cited elsewhere by J.A. Udden, C.L. Baker, W.S. Adkins, and P.B. King, it can fairly be said that Ross Maxwell, and the "et al," John T. Lonsdale (igneous petrology), Roy Hazzard (invertebrate paleontology), and John A. Wilson (vertebrate biostratigraphy) built the foundations for the study of geology in the Big Bend in much the same sense that King established the universe of discourse for discussion of the geology of the Precambrian and Paleozoic to the north from Sierra Blanca to Marathon. This field trip is about the geology of the Tertiary, rocks and events, in the Big Bend region; it is a progress report attempting to show the nature of some of the advances in understanding of that part of geology that has been achieved in the past 20 years. There have been radical changes in the thinking of geologists everywhere during that time; no less in the Big Bend. But the foundation remains.

The geology of the Big Bend region was the subject of field trips in the '40's and '50's, but the unveiling of something like a finished product was a field trip organized by the West Texas Geological Society in 1965, led by Ross Maxwell and John Dietrich. The trip was a great success, and the accompanying guidebook, reprinted with some additions when the fieldtrip was re-run in 1972, remains as the most complete guidebook for the region as a whole. This guidebook owes a lot to that one.



TEXAS
Alpine
90
Marfa
Marathon
385
118
N
Study Butte
170
BIG BEND NATIONAL PARK
Lajitas
Castolon

FIGURE 1

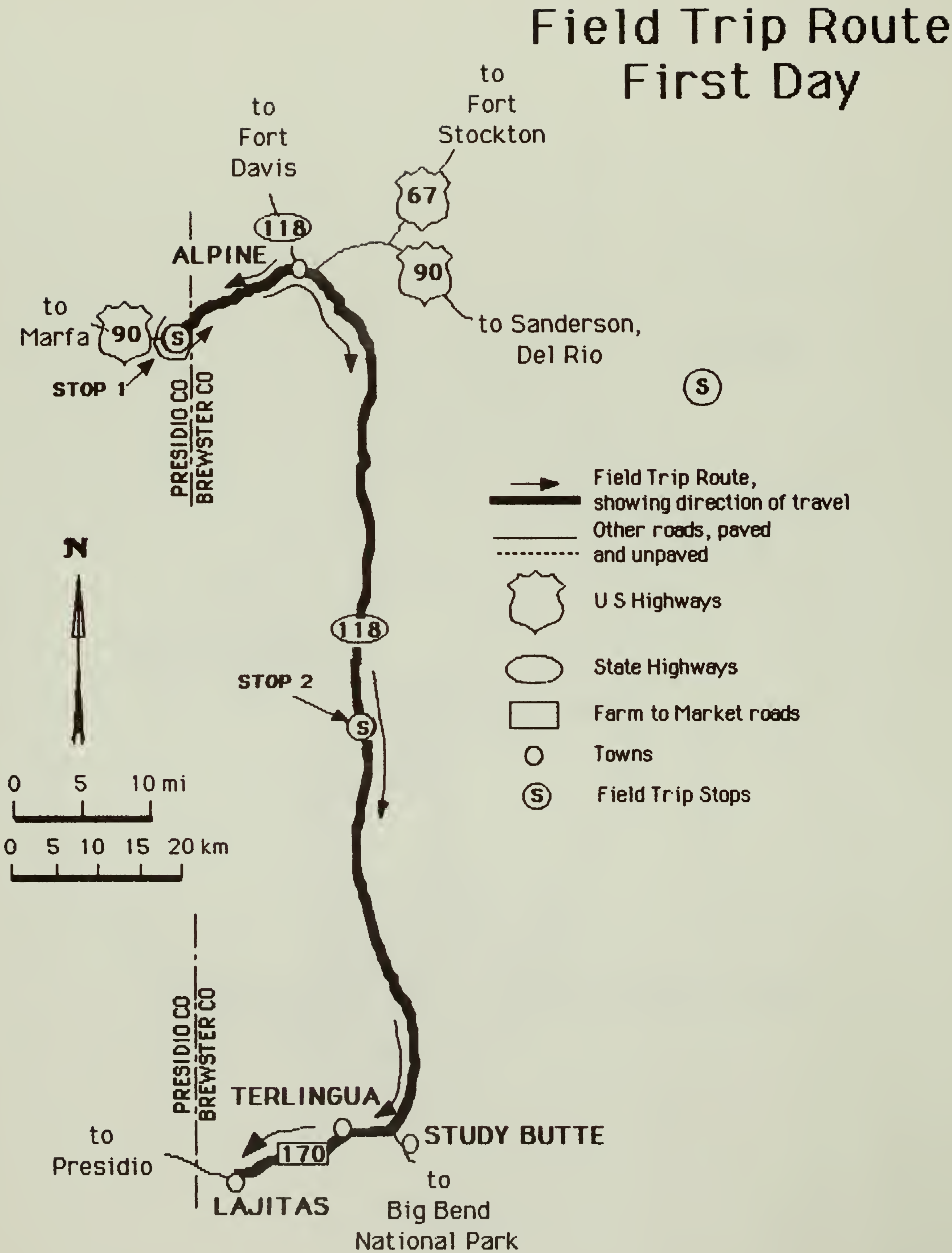

Field Trip Route
First Day
to
Fort
Stockton
to
Fort
Davis
67
118
ALPINE
90
to
Marfa
90
S
to Sanderson,
Del Rio
S
STOP 1
PRESIDIO CO
BREWSTER CO
Field Trip Route,
showing direction of travel
Other roads, paved
and unpaved
U S Highways
State Highways
Farm to Market roads
Towns
Field Trip Stops
N
118
STOP 2
S
0 5 10 mi
0 5 10 15 20 km
PRESIDIO CO
BREWSTER CO
TERLINGUA
to
Presidio
170
STUDY BUTTE
LAJITAS
to
Big Bend
National Park

FIGURE 2

ROAD LOG, DAY 1
ALPINE, WEST TO PAISANO PASS AND BACK, THEN SOUTH TO LAJITAS
(Figure 2)

0.0 0.0 Southern Pacific Railroad Station, Alpine, Texas elevation 4485 ft. (1367m).

Alpine in the early days was called either Osborne or Murphyville (1882), but received its present name in 1888. Alpine is the county seat of Brewster County, the largest county in Texas, and the home of Sul Ross State University, founded in 1917. Sul Ross offers a broad undergraduate curriculum with emphasis in Education and Range Animal Science, and has, as well, several master's degree programs including geology. The intercollegiate sport attracting the greatest attention, on and off campus, is Rodeo. Currently there are about 1,600 students in attendance.

We will go one block north and turn west on US 90. As we go west out of town we have an edge-on view of the eroded remains of a trachyte-quartz trachyte shield volcano, interrupted by, generally trachytic, or microsyenitic, intrusive masses which form the higher peaks: Twin Pks (the Twin Sisters) to the southwest, the Haystacks, ahead, north of the highway, and the sharply conical Mitre Pk to the northwest. To the northwest, low, are low hills of the mafic (mugearite) flows that preceded the building of the volcano.

4.1 4.1 Bridge over McIntyre Creek.

5.8 1.7 Roadside park; in this area we have roadcuts and low hills of the light colored rhyolite that is the lowest unit in the Decie Fm. Dikes (trachytes, or materials very similar to the host rock) hold up low, sharp ridges. The high walls that surround us are the shield-building units (trachyte and quartz trachyte) of the volcano. The flat-topped mountain ahead is Paisano Pk.

7.5 1.7 Roadcut in paisanitic rock cut by a variety of dikes, mostly trachytic. The roadcut grazes one of the dikes, displaying unusually well the flow structure in the chilled margin.

Classification of Igneous Rocks

With special application to the Paisano Volcano and general reference to rocks of the Cenozoic Volcanic Field Trans-Pecos Texas

(Modified from Parker, 1983)

BASALT	DI > 30; normative plagioclase > An_{50}	
HAWAIITE	DI = 30 - 45; normative plagioclase An_{30-50}	
MUGEARITE	DI = 45 - 65; normative plagioclase < An_{30}	
BENMOREITE	DI = 65 - 75	
TRACHYTE	DI > 75	normative quartz < 10%
QUARTZ TRACHYTE	DI > 75	normative quartz 10 - 20%
RHYOLITE	DI > 75	normative quartz ≥ 20%
COMENDITE	Peralkaline Rhyolite; rhyolites of the Paisano volcano are, in general, Comendites	

DI: DIFFERENTIATION INDEX, the sum of normative percentages of quartz, orthoclase, albite, nepheline, leucite, and kaliophilite (Thornton and Tuttle, 1960).

PERALKALINE: applies to igneous rocks with a molecular percentage of alumina less than the sum of the molecular percentages of soda and potassium oxide.

FIGURE 3

9.9 2.4 Stop 1; after we debark, the bus will go and find a place to turn around. We are, barely, in the Paisano Pass Caldera, a collapsed caldera, that produced the rhyolite that is the basal of the three units that formed a volcano in this area. I do not understand this road cut, at least in any detail, but it provided an opportunity to see what volcanic geology can be like, to talk about volcanism in the Big Bend region, and to share my confusion with you.

Most of this trip, though in a major volcanic province, will be concerned with sedimentary rocks, and the tectonism and structures that have influenced their deposition. It seems reasonable, however, to make one stop (possibly two) in an accessible area that displays volcanic geology at its best (or worst, depending on one's point of view).

The Paisano Volcano, which occupies the area between Alpine and the Marfa Bolson, was studied and named by Don F. Parker (Parker, 1976, 1979, 1983; Parker and McDowell, 1979), and what little I know of the area comes mainly from these publications and conversations with Parker, and with Daniel Gorski who worked in the area around Mitre Pk (Gorski, 1970). Many of the rock types used by Parker and others (particularly Barker, 1977, 1979) who have discussed igneous rocks of the Cenozoic volcanic field of Trans-Pecos Texas, may not be entirely familiar. Fig 3 provides a short guide to some of the more common uncommon names.

Building of the volcano began at about 35 ma, and was contemporaneous with, to slightly younger than, most of the volcanic activity to the north and to the south in the Davis Mts. The shield of the volcano is about 12.4 by 18.6 mi (20 by 30 km), elongate northwest-southeast. Preliminary mafic (mugearite) eruption was followed by lava dome and explosive eruption of paisanitic peralkaline rhyolite (comendite) and associated ash flow tuff in and from a small (3.1 mi, or 5 km diameter) caldera that eventually collapsed. This was succeeded, in fairly short order by eruption of the main shield, trachytes, and quartz trachytes, in two distinct units. Eruption of the shield was from radial dike swarms that mark an area about 5 mi (8 km) in diameter, and according to Parker, are a rough indication of the diameter of the magma diapir from which

the lavas were derived. The rhyolites and the trachytes that together make up the Paisano Volcano, Parker named the Decie Fm. After the building of the volcano, there was a brief return to fissure eruptions of mugearite.

Paisanite is a very handsome variety of rhyolite: ideally it has undeformed sunburst aggregates of very tiny crystals of blue alkali amphibole (or pyroxene, elsewhere) in an aphyric, near white matrix. Most geologists can ignore Paisanite with impunity, but in the Big Bend country there is a lot of it along a narrow northwesterly trend that extends into New Mexico. As a soft rock geologist, I appreciate it because it is easy to identify. According to Gorski (1970), a minor intrusion at the foot of Mitre Pk is the true type locality of the rock. The name "Paisanite," for Paisano Pk, is the result of confusion in the locality for samples from which Osann (1896) described the rock. On the other hand, Paisano Pk is a paisanitic intrustion (microsyenite; abudnant flow foliation is marked by deformed sunbursts in a pale blue-grey aphyric matrix).

Paisanitic rhyolites and close relatives provide a very useful kind of sedimentary clast (they can be recognized in thin sections of medium sandstones) that can mark clearly the progress of unroofing of structures. They are also a bit of a problem, since their expansion seems to be westward from the Cenozoic volcanic field of Trans-Pecos Texas into Chihuahua, rather than the reverse (Cameron et al, 1980). Andesite-related (calc-alkalic or alkali-calcic) volcanism, particularly in western Mexico and adjacent parts of the United States does show an eastward progression, that has been taken as marking the progress of subduction of the Farallon Plate, at a fairly high rate of speed; the peralkaline comendites and their relatives found in this volcanic pile seem to require a different model.

Many of you may have noticed a roadcut 2.4 mi (4 km) back that grazes, and very effectively exposes a trachyte dike. If there is any general desire to do so, and time permits, we can make a brief auxilliary stop there.

12.3 2.4 Returning to Alpine; road cut in a trachyte dike that cuts the paisanitic rhyolite. The dike has a well developed chilled margin, including a vitrophyre, that shows flow structure very effecitvely.

19.7 7.4 Back in front of the railway station; to the south (right), across the tracks, you can see what was once the main street of Alpine with buildings, now in considerable disrepair, that date back more than a century, to the Murphyville days of the town.

20.7 1.0 Turn south (right) on TX 118 at the junction with US 90. The road log, including this entry, from this point down to the 02 Flats, some 35 mi (56 km) south, is modified from Maxwell and Dietrich (1965, p. 163-167). The high, rounded hill to the northeast is the Sul Ross [College] Hill (or Hancock Hill, or 06 Hill), composed of Crossen Trachyte, probably domed by an unexposed intrusive. A 2,000 ft (610 m) water well on the west side of the hill penetrated Cretaceous and Paleozoic (Permian, presumably) rocks.

21.3 0.6 Alpine city limit; the hill to the south, on the right ("A" Hill) is a syenite intrusion.

24.1 2.8 Crossen Trachyte, a volcanic mbr of the Pruett Fm (Goldich and Elms, 1949), crops out on both sides of the road. Maxwell and Dietrich (1965) reported an undocumented date for the Crossen Trachyte that would recalculate as 38.8 ma. It is hard to be sure, but the dated sample probably came from further south, where the stratigraphic position of the Crossen is better known.

25.4 1.3 Hill on the left and the several knobs around it are Sheep Canyon Mbr, "basalt," Pruett Fm. The large hill is capped by Potato Hill Andesite. Clark and Gilliland (1978) reported K-Ar dates which would recalculate to 36.9, and 36.5 ma, respectively, for these units. Although no documentation is given for these dates, they are in stratigraphic order, and in general agreement with other dates from the volcanic rocks of the Buck Hill Group, and the Decie Fm. The ages and stratigraphic position suggest the possibility of a connection between these rocks with the mugearites that preceded the building of the Paisano Volcano.

26.0 0.6 Syenite "dike" to the left side of the road.

27.6 1.6 There is a good view of the town of Alpine and the Sul Ross State University campus as we climb up what is locally called "Big Hill,"

composed of Crossen Trachyte; there are at three other places called "Big Hill" in this part of Texas. Ridges across the canyon on the right are syenite, part of a large intrusion which elevated Crossen Trachyte. Similar intrustions form the skyline to the northwest, such as Ranger Pk, Twin Pks (Twin Sisters), Haystack Mtn, and Mitre Pk.

29.6 2.0 Light-colored rocks in the distance to the northeast (left ahead) are Cretaceous limestones dipping west off of the Marathon Uplift. The name Georgetown, used in the past for these rocks might now reasonably be replaced by Santa Elena Fm, described from Big Bend National Park by Maxwell (in Maxwell et al, 1967), and now used more widely.

31.3 1.7 Cottonwood Spring Fm on both sides of the road. This is the divide between the Rio Grande and Pecos River drainage basins, elevation 5,404 feet (1647 m).

31.6 0.3 Potato Hill Andesite exposed in the roadcut at 3:00.

31.8 0.2 Ruff overlying Sheep Canyon Mbr, Pruett Fm, exposed in road cut at 3:00.

32.1 0.3 Top of the Sheep Canyon Mbr; Mount Ord in the distance to the left has an elevation of 6,850 ft (2088 m), the highest peak of the Del Norte Mts.

32.2 0.1 More tuff above the Sheep Canyon Mbr exposed in the roadcut at 3:00.

33.9 1.7 The small rounded hill on the left is capped by Potato Hill Andesite which overlies Sheep Canyon Mbr, exposed in the slope. Sheep Canyon Mbr, Potato Hill Andesite, and Cottonwood Spring Fm make up the slope and summit of the ridge on the right. Here, a flow in the Sheep Canyon Mbr contains large, black phenocrysts of hypersthene.

34.5 0.6 Cattle guard at 9:00.

35.6 1.1 At 3:00 is the entrance to the Cathedral Mountain Lodge which was destroyed by fire more than twenty years ago. The buildings were headquarters for the old Haley Ranch. The butte-like mountain in the distance on the right is Haley Mtn, capped by a sill of microsyenite. To the northwest (right) of Haley Mtn is McIntyre Pk, a syenite intrusive. The higher peak to the southwest (left) of Haley Mtn is Cathedral Mtn capped by a basalt which may or may not be part of the Rawls Fm.

37.0 1.4 Mount Ord (6,850 ft or 2099 m), is seen on the left. Mount Ord is capped by Crossen Trachyte as a "cuesta" peak. Tertiary volcanic rocks are bowed around the west side of a large dome located about three-fourths of a mile (1.2 km) east-northeast of Mount Ord. The lava cap breaks off abruptly on the east and northeast side of the mountain, surmounting a steep cuesta inface overlooking the Del Norte Mts. Mount Ord is the extreme northeast corner of the Cathedral Mtn (15') quadrange mapped by McAnulty (1955), whose work, building on that of Goldich and Seward (1948) and Goldich and Elms (1949), established the Tertiary stratigraphy of the Southern Davis Mts.

37.6 0.6 Road to the right goes to the Woodward Ranch, nationally known as a mecca for "rock hounds" interested in searching locally for, or purchasing agate. Highly prized plume and moss agates occur in amygdaloidal zones of the Sheep Canyon and Cottonwood Spring flows, banded pastel agate occurs in the Crossen Trachyte, and bloodstone is common in the Potato Hill Andesite. Gem quality labradorite crystals occur as phenocrysts in mugearites of the Sheep Canyon Mbr.

37.9 0.3 Entrance to the Lassiter Ranch at 3:00; sign reads Red House Ranch.

38.0 0.1 Cottonwood Spring Fm ("basalt") on both sides of the road. To the right in the distance is Cienego Mtn, an eroded trap-door dome in which the intrusive core of paisanitic microsyenite raised the "door" so high that parallel faults on the northeast and southwest sides and the end fault across the southeast side are obscured by the intrusive mass. The core of Cienega Mountain is part of a large intrusive body which crops out over an area of 12.4 sq mi (32 sq km). The intrusion extends from Little Cienega Mtn to the south to Cathedral Mtn and beyond to the north, having the proportions of a large stock. The intrusion arched Cretaceous sedimentary and Tertiary volcanic rocks on the northwest side of the mountain. Erosional remnants of basal Cretaceous rocks located on the highest part of the mountain indicate the rocks now dipping off the northwest slope once extended over the summit. Cathedral Mtn is a highly faulted erosional remnant of the early to middle Tertiary Buck Hill Group. The spire and upper bench is ?Rawls "basalt." Beneath this "Basalt" is Tascotal Fm (near white tuffaceous, or

zeolitized volcaniclastic sediments), Mitchell Mesa Fm (rhyolite; an ignimbrite sheet) as the second bench; Duff Fm (similar to, but redder than the Tascotal Fm) forms the slopes below.

38.4 0.4 Contact between Potato Hill Andesite and Cottonwood Spring Fm (mugearite) in the road cut at 3:00.

39.4 1.0 Crossen Trachyte on both sides of the road.

40.4 1.0 Sheep Canyon Mbr, Pruett Fm, Potato Hill Andesite, and Cottonwood Spring FM in the hills on the left.

40.8 0.4 Inlier of Crossen Trachyte at 3:00.

41.0 0.2 Inlier of Crossen Trachyte at 3:00. Sheep Canyon Mbr, Potato Hill Andesite, and Cottonwood Spring Fm in the hills to the left.

41.2 0.2 Sheep Canyon Mbr, Pruett Fm, in the road cut; Potato Hill Andesite and Cottonwood Spring Fm are the dark rocks in slopes on either side.

41.7 0.5 Sheep Canyon Mbr in road cut at 9:00.

41.9 0.2 Road crosses the Calamity Creek Fault; Cottonwood Spring Fm on the southwest side has been dropped against the Crossen Trachyte on the northeast. This northwesterly striking fault passes between Elephant Mountain and Calamity Creek to the south, and continues along the east side of the creek for 12.5 mi (20.1 km) to a point south of Haley Mountain. Displacement varies from 300 to 500 ft (91 - 152 m).

42.2 0.3 Highway bridge across Calamity Creek. Springs feed the creek and there is always water along this stretch, but the water goes under ground just north of the old Neville Ranch house.

42.3 0.1 Cottonwood Spring Fm in the road cut at 3:00, and along the scarp beside the creek at 9:00.

42.8 0.5 Contact between Sheep Canyon Mbr, Pruett Fm, and Potato Hill Andesite. Small hills on the left and the hill on the right are capped by "basalt" of the Cottonwood Spring Fm. For the next 3 mi (4.8 km) the road lies on top of the Sheep Canyon Mbr.

44.5 1.7 Tuff within the Sheep Canyon Mbr in the road cut at 3:00.

44.9 0.4 Good exposure of Sheep Canyon "basalt" in road cut at 9:00.

45.4 0.5 Cattle guard at 9:00, road into the old Neville Ranch headquarters.

45.9 0.5 Tuffs of the Pruett Fm are exposed in road cut at 3:00, overlain by Sheep Canyon Mbr; Calamity Creek at 9:00.

46.4 0.5 At 3:00 Sheep Canyon Mbr rests on Pruett Fm sedimentary rocks. The Crossen Trachyte reappears in the escarpment to the northeast across Calamity Creek and beyond the Neville Ranch headquarters on the left.

46.6 0.2 Pruett Formation (tuff) in the road cut at 3:00.

47.1 0.5 Roadside park at 9:00; on the right side of the road nonmarine Tertiary limestones some 300 ft (91 m) thick occur, possibly within the Pruett Fm, and are well exposed. The upper 200 ft (61 m) is light gray to brown, fine-grained, thick bedded, algal limestone with charophytes, fossil gastropods (Goniobasis Tenera Carterii?) and ostracods, which Goldich and Elms (1949) tentatively regarded as Eocene. Vertebrate fossils found in 1955 indicate a possible Duchesnean (late Middle Eocene to early Late Eocene) age for the lower part of the basal sediments of the Pruett Fm. Limestone beds 3 to 10 feet thick are common in the Pruett tuff, the Sheep Canyon Mbr, and the Chadronian (Eocene - Oligocen) bandera Mesa Mbr, Deveil's Graveyard Fm exposed nerly 20 mi (32 km) to the west. Thick accumulations, however, such as this one occur only here in the big re-entrant of the escarpment along the west side of Chalk Valley, and in the Mount Ord Basin. Here and in the Mount Ord Basin the Crossen Trachyte is absent because of pre-Sheep Canyon erosion (?), and the Sheep Canyon Mbr rests directly on limestone and tuff continuous (?) with the Pruett Fm. Therefore it is possible that all or part of this limestone may be post-Crossen in age.

The limestone was studied by Beroni (1954), and more recently and in more detail by Robinson (1978); in both instances because of its uranium content and striking algal development. Folk and Pittman (1971) included samples from this limestone in their study of the occurrence of length-slow chalcedony, an indicator of evaporitic conditions. It is probable that the lakes in which the limestone was deposited were highly saline.

48.1 1.0 The light colored rock on the right is fresh-water limestone in the Pruett Fm; the section behind us is partially duplicated by faulting.

48.8 0.7 Highway bridge across Sheep Creek; the junction with Calamity Creek is about 350 ft to the left of the bridge. Albritton and Bryan

(1939), on the basis of disconformities, divided the valley fill in this area into the Neville (oldest), Calamity, and Kokernot (youngest) fms. Good exposures of Neville and Calamity fms may be seen in the creek banks immediately down stream from this bridge.

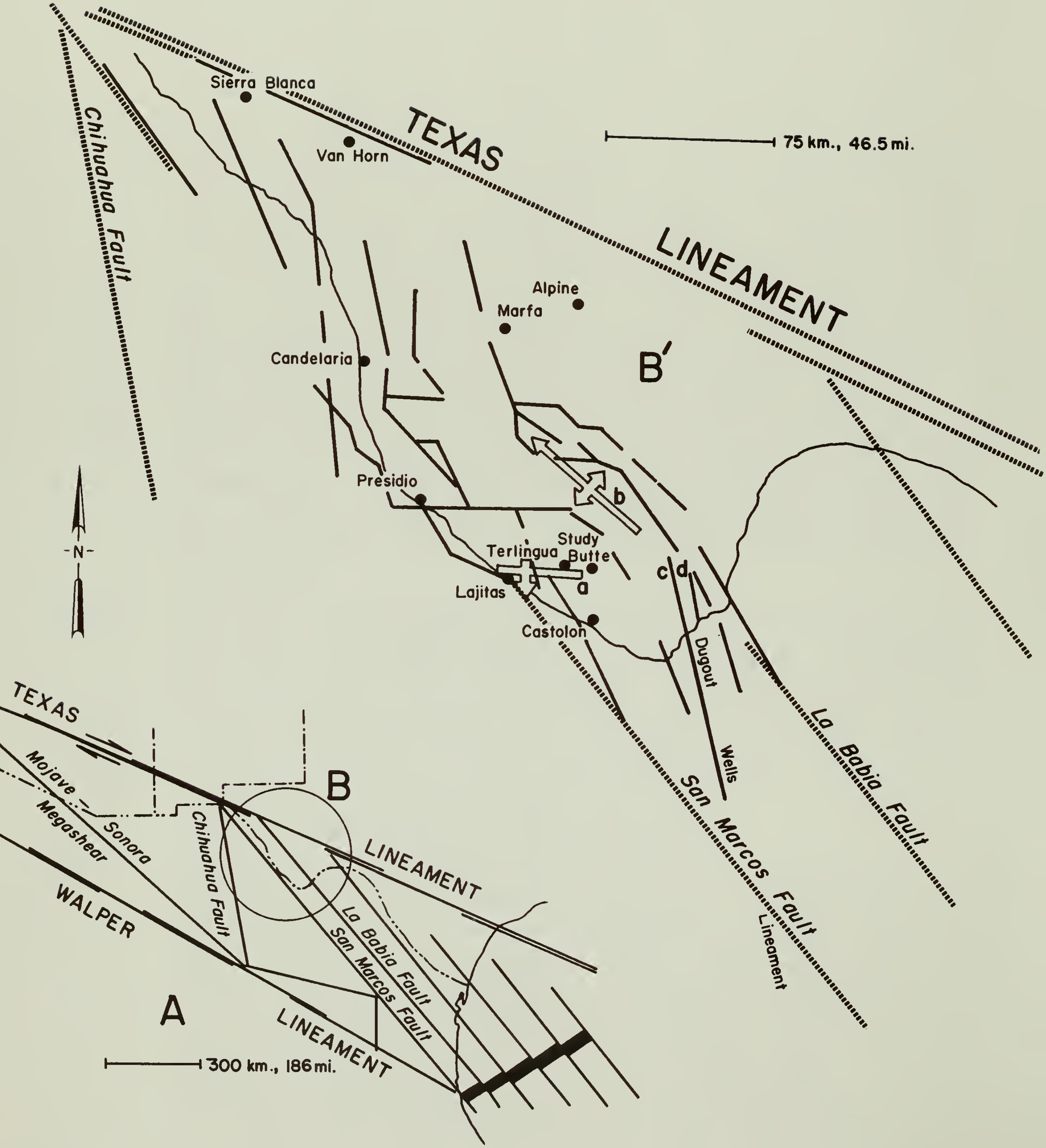
50.8 2.0 We are 30 mi (48 km) from Alpine, leaving the Cathedral Mtn, and entering the Buck Hill (15') quadrangle, the area studied by Goldich and Elms (1949). Notice the canyon to the right, eroded into the Torvea Canyon Fault, downthrown to teh southwest. The fault can be traced for 6 mi (9.7 km) in a northwesterly direction almost to Goat Mtn. There is another Goat Mtn in Big Bend National Park. Displacement increases from about 115 ft (35 m) here, to 300-400 ft (91 - 122 m) along the west side of Crossen (Kokernot) Mesa.

51.7 0.9 Cattle guard at 3:00, road into the old Lee Kokernot ranch house.

51.8 0.1 Cattle guard at 9:00, road to the old W. Herbert Kokernot Ranch headquarters. The slopes of Elephant Mtn to the left at 7:00 - 8:00 are exposures of basal Pruett Fm, tuffaceous sedimenary rocks, and Sheep Canyon Mbr. The flat capping rock is a sill of paisanitic microsyenite.

54.0 2.2 The notch in the mountains across Kokernot Flats on the left is Del Norte Gap, the boundary between the Santiago Mts on the southeast and the Del Norte Mts on the northwest. In the early part of this century, mercury was hauled from Terlinguar up the present line of TX 118, but about a mile and a half north of Buck Hill, the road turned northeast to Del Norte Gap and on through the (then) town of Monument Springs to the railhead at Marathon.

54.9 0.9 Cattle guard on the right, road to the 02 Ranch headquarters, is bladed on Boquillas limestone. This road also allows (currently restricted) access to the Green Valley-Paradise Valley areas and Puerto Potrillo. The escarpment to the right ahead forms the southen boundary of the Davis Mtns. The slope on Crossen Mesa to the right at 3:30-5:00 is developed on Pruett Fm. The top of the mesa is Crossen Trachyte. We are near the point where a break in slope across the Walnut Draw Fault will drop us from Kikernot to 02 flats, with good view of the escarpment to the right and the Walnut Draw Fault Zone at 4:00, as it continues to the west-northwest. Cumulative displacement along this fault zone is about 1100 ft (225



TEXAS
LINEAMENT
Chihuahua Fault
Sierra Blanca
Van Horn
75 km., 46.5 mi.
Alpine
Marfa
Candelaria
B′
Presidio
b
Study
Terlingua
Butte
a
c
d
Lajitas
Castolon
Dugout
Wells
Lineament
La Babia Fault
San Marcos Fault
N
TEXAS
Mojave
Megashear
Sonora
Chihuahua Fault
B
LINEAMENT
WALPER
La Babia Fault
San Marcos Fault
A
LINEAMENT
300 km., 186 mi.

FIGURE 4

m) (Goldich, 1949). To the left of Walnut Draw at 4:00 are hills of Pruett Fm overlain by Cottonwood Spring Fm ("Basalt"), in the downthrown side of the Walnut Draw Fault, near the type localities of these formations.

55.6 0.7 Stop 2, along the road, on the upthrown (among other things, probably) side of the Walnut Draw Fault; elevation about 4100 ft (1250 m). The topographic relief that we have experienced since climbing up Alpine's "Big Hill," where Crossen Trachyte has been punched up out of position by a stock-like intrusion, and the Pecos-Rio Grande divide, could be generalized as a gradual descent through the Buck Hill Group. We are now standing on the Pretertiary basement. Basement is presented here by lowermost Gulfian Boquillas Fm, a thin, bedded cream to yellow limestone, that we will see often for the rest of the day. Beyond the Walnut Draw-Chalk Draw fault system (we will cross a divergent east-west part of the Chalk Draw Fault about 9.6 mi, or 15.5 km further south), we begin a stepwise, but, in structural terms, more definite descent, so that at Lajitas we can stand again on Boquillas Fm, but at an elevation of 2342 ft (714 m).

Figs 4 and 5 are an attempt to present, in increasingly particular detail, both theory (Fig 4a, Fig 5) and some degree of reality (Fig 4b), the tectonic setting of the Sunken Block. To the east, the Santiago Mts, and part of the Chalk Fault, align well with the general trend of the Walnut Draw Fault Zone, which, in turn, along a course that would graze the Paisano Caldera, aligns with faults beyond it to the northwest, approaching the Texas Lineament. The Santiago Mts run southeast from Del Norte Gap to end officially at Persimon Gap. That complex area is strategically located at the approximate intersection of a number of different trends, to be discussed when we get there. From Dog Canyon just southeast of the gap, the trend of the Del Carmen Mts marks a more northerly strike for the southern part of the trend, but still coincides approximately with Longoria's (1985) La Babia Fault. The northeastern side of the Udden's (1907) Sunken Block runs from approximately our present position southeast into Coahila, Mexico. The western side is marked, from northwest to southeast, by the West

FIG. 4A, Tectonic Transpression Model, southwestern United States-northern Mexico, as proposed by Longoria (1985). Vectors on Texas Lineament reflect Jurassic right-lateral movement. B, Trans-Pecos Texas, enlarged in B'. B', Detail of tectonic transpression, Trans-Pecos Texas, modified from Dickerson (1980), Muehlberger (1980), and Stevens and Stevens (1983): (a), Terlingua Monocline; (b), broad, plunging arch between Santiago Range on the northeast and Tertiary rocks to the southwest; (c), Dugout Wells lineament (new) and (d), Desert Spring fault (new), two tectonic elements separating the Chisos and Estufa sub-blocks, Big Bend National Park, which cut older gravels of Maxwell et al (1967) at least as young as Pleistocene. Checkered faults represent selected parts of trends illustrated by Longoria (1985).

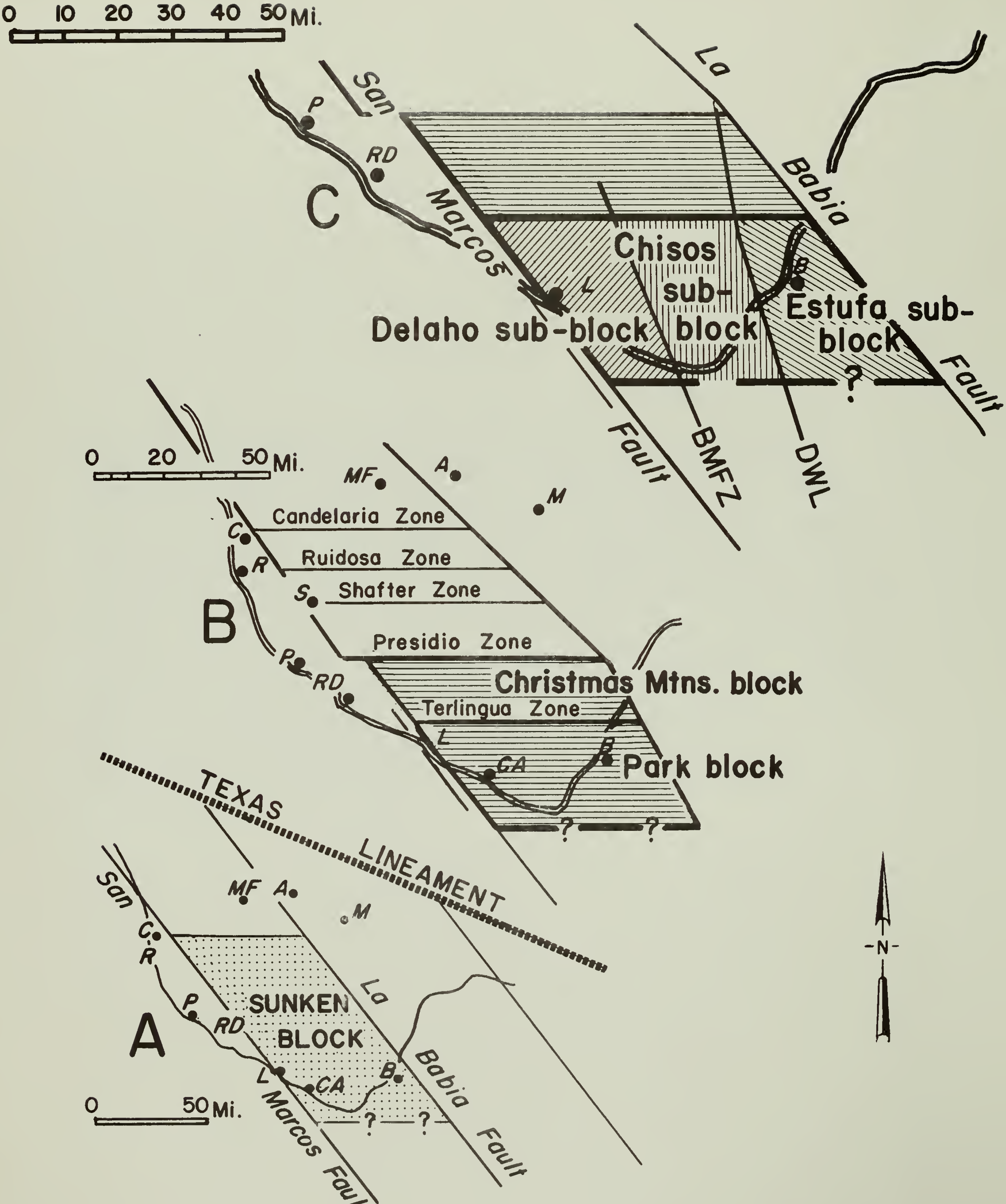

0 10 20 30 40 50 Mi.
C
San
Marcos
La
Babia
Fault
P
RD
Chisos
sub-
block
Estufa sub-
block
Delaho sub-block
?
Fault
BMFZ
DWL
0 20 50 Mi.
B
MF
A
M
Candelaria Zone
Ruidosa Zone
Shafter Zone
Presidio Zone
Christmas Mtns. block
Terlingua Zone
Park block
C
R
S
P
RD
L
CA
B
?
?
TEXAS
LINEAMENT
A
San
Marcos
Fault
MF
A
M
C
R
P
RD
SUNKEN
BLOCK
L
CA
B
La
Babia
Fault
?
?
0 50 Mi.
N

FIGURE 5

FIG. 5. Progressive increased resolution of tectonic elements for the Sunken Block as defined in this report. (A), The Sunken Block relative Longoria's (1985) lineations. (B), Transverse zones (Dickerson, 1980) of weakness subdividing the Sunken Block, and location of the Christmas Mtns and Park blocks. (C), Subdivisions of the Park block; BMFZ, Burro Mesa Fault Zone; DWL, Dugout Wells Lineament. Explanation of other map symbols: A, Alpine; B, Boquillas; C, Candelaria; CA, Castolon; L, Lajitas; M, Marathon; MF, Marfa, P, Presidio; R, Ruidosa; RF, Redford, S, Shafter.

Chinati Fault Zone, which, further to the southeast in extreme eastern Chihuahua and beyond, approximately coincides with Longoria's San Marcos Fault. These northwest-striking boundaries would be second second order trends in a shearing zone between the Texas Lineament and the "Walper" megashear in Mexico.

Internally the Sunken Block is much subdivided. Figure 5 attempts to organize a geometrically simplified developmental view of the general structural outlines of the Sunken Block. The (nearly east-west trends are the zones that were proposed by Dickerson (1980); specifically, from north to south, the Shafter Zone (marked in the immediate area by the east-west part of the Chalk Draw Fault, and east-west trends in the Walnut Draw Fault Zone), the Presidio Zone, the Terlingua Zone (which meets the Terlingua Fault Zone near Lajitas), and something that ought to exist in the neighborhood of, or south of, the Santa Elena Zone. These are old zones of weakness, though most or all show some modern movement. There is major geophysical evidence marking the Shafter Zone (Dickerson, 1980; Pearson (1978, 1981) suggests cumulative (ordovician-Permian, and younger) down-to-the-north displacment possibly in excess of 10,000 ft (3048 m) on the Shafter Zone in eastern Presidio County. In the Cenozoic, the block between the Shafter and Presidio zones tilted to the south and west, with relatively little movement on the east-west part of the Chalk Draw Fault. Apparent motion on the Presidio, and Terlingua zones can be generalized as down-to-the-south, more strongly so on the latter. The blocks may have rotated slightly, so that the east end is higher (perhaps the up-warp of Cretaceous rocks that King (1935) showed). However, the blocks defined by the northwest-striking and east-west striking trends are themselves subdivided, most commonly by northwest trending fault zones that overprint the east-west trends in many places, and greatly complicate the internal appearance of the blocks. As we shall see, these subdivision do not show unanimty of movement.

Bruce Pearson, in a note (personal communication, 1986) made an interesting suggestion about the possibility of lateral motion on the Walnut Draw Fault Zone. Since it fits well with my predjudices, his sketch map is, with his permission, reproduced in Fig 6. Figure

6A shows his earlier interpretation, and 6B shows a possible interpretation that would be consistent with right lateral movement, and has the virtue of offering an explanation for disturbance of the Ouachita Front that he had observed earlier. For future reference, note the possibility of left lateral movement on the Chalk Draw Fault.

After this interlude of arm-waving, we will re-board the bus, and continue, literally, down south.

59.8 4.2 Highway bridge over a part of Calamity Creek. Efforts to halt erosion have lead to the partial diversion of Calamity Creek, which used to be continuous with Terlingua Creek. Now much of the run-off from Calamity Creek goes into Maravillas Creek, which drains the west side of the Marathon Basin. Local ranchers claim that when Calamity Creek "really rolls" some of its water still goes into Terlingua Creek.

62.1 2.3 More of the 02 Flat with Butcherknife hill (a small intrusion) to the west at 3:00.

63.2 1.1 Highway sign says "Santiago Peak, elevation 6521 feet" (6521 ft = 1988 m).

66.2 3.0 Road crosses the east-west (here) Chalk Draw Fault. To the east (about 9:00) the fault runs at the base of the north side of exposures of uppermost Comanchean Buda Fm (white limestone) overlying Del Rio Fm (grey-brown shale); to the west (about 2:30) it cuts of the north end of Buck Hill, a small, faulted, sill-like intrusion surrounded by exposures of Devill's Graveyard Fm (Eocene-Oligocene).

70.5 4.3 Highway sign reads "Big Bend National Park 60 miles".

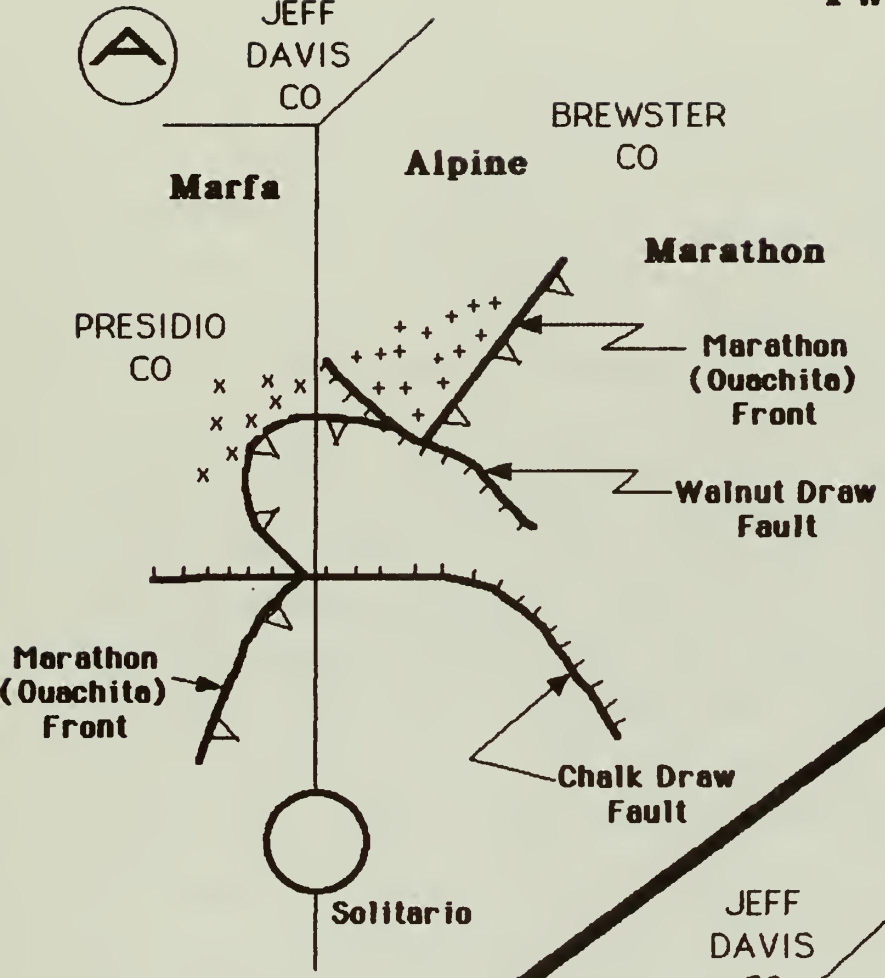
73.9 3.4 Fence line to the right across Boquillas limestone, forms the southern boundary of the 02 Ranch. We crossed the northern boundary about 20 mi (32 km) back.

77.4 3.5 Santiago Pk at 8:00, Nine Point Mesa at 9:00-10:00, Hen Egg Mtn at 1:30, Solitario rim at 2:15, Devil's Graveyard badlands (Devil's Graveyard Formation, Eocene-Oligocene) due west at 3:00, Tascotal Mesa forms skyline behind. At about 32 ma, the Solitario was being uplifted (Wilson et al, 1979), and the Mitchell Mesa Rhyolite, which tops Bandera Mesa, the bench below Tascotal Mesa, was erupted from

Two Interpretations of the Walnut Draw & Chalk Draw Faults, from Bruce Pearson

Left: Pearson, 1978

Below: Pearson (personal communication, 1986), an interesting alternative.



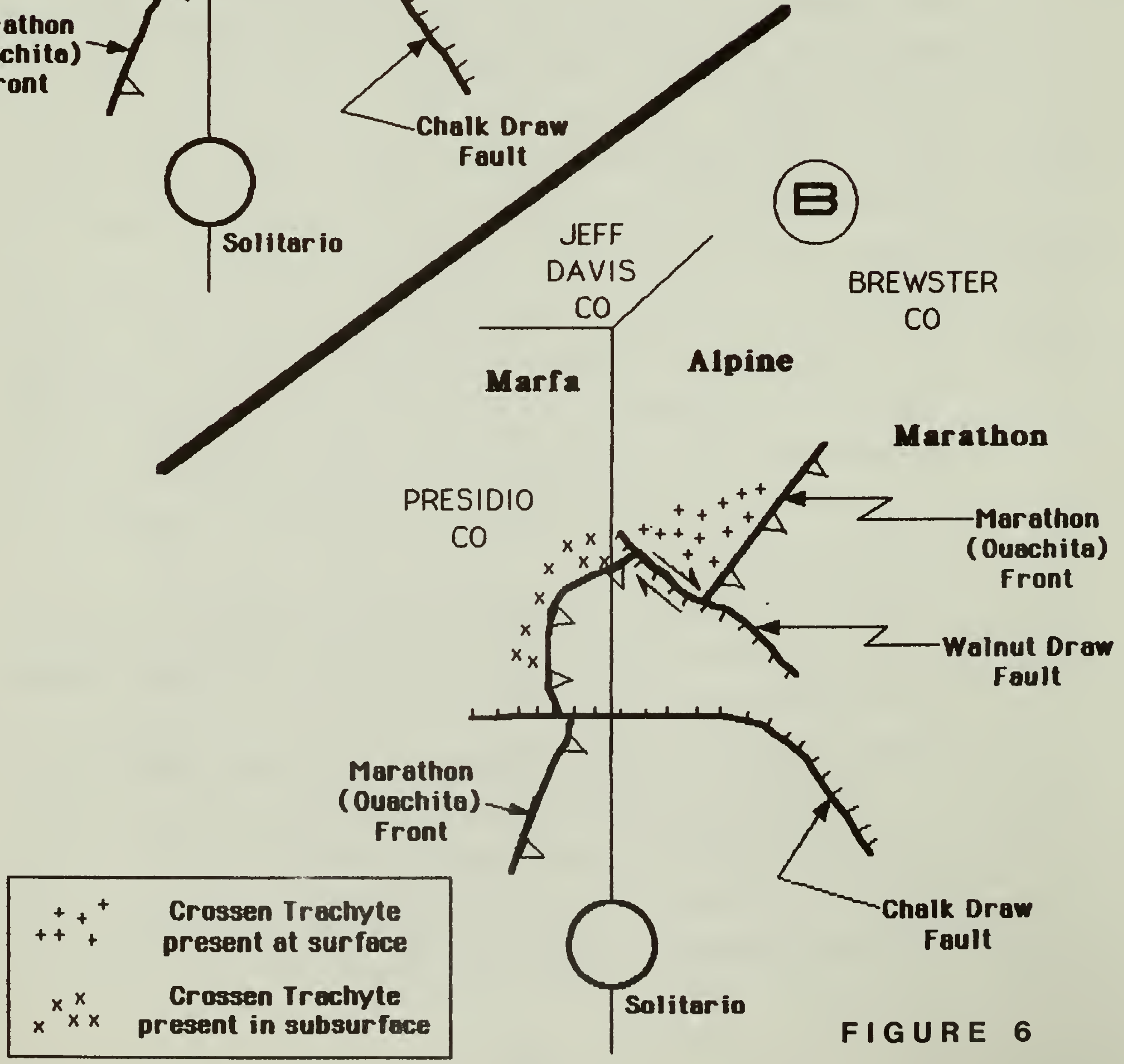


FIGURE 6

the Chinati Caldera according to Cepeda and Henry (1983).

77.9 0.5 American Legion Hall.

79.1 1.2 Nine Point Mesa, capped by a thick (up to about 1000 ft or 305 m) sill of paisanitic rhyolite (comendite?) is seen to the east at 9:00, and to the left of the mesa is Black Hill, a Tertiary intrusion. As we go south of Nine Point Mesa we will cross the Presidio Zone referred to at the last stop.

80.3 1.2 Gravel road to the right provides access to the Agua Fria, Fizzle Flat, and Devil's Graveyard areas. Agua Fria Mtn, elevation 4828 ft (1472 m), is seen to the west, right. The mountain appears flat-topped but is deeply dissected; it is a stock-like intrusion (Moon, 1953) of paisanitic rhyolite (comendite) about 2 mi (3.2 km) in diameter. It intruded the Gulfian Cretaceous and at least the basal part of the Devil's Graveyard Fm with much local fracturing. The Eocene-Oligocene Devil's Graveyard Fm, about 1500 ft (457 m) thick, is exposed almost continuously from Agua Fria Mtn to an arbitrary east-west boundary with the Pruett Fm, about 20 mi (32 km) to the northwest, near McKinney Mtn.

80.9 0.6 On the east (left) the Camel, a local watering place.

82.7 1.8 Next to the Baptist Church, a fault separating Lower from Upper Cretaceous rocks.

83.4 0.7 White Mill Road to the left; the original landmark (the white windmill) no longer stands. The road currently gives access to the Terlingua Ranch estates but can be used, in good weather, to go to Persimmon Gap. To the north (left) of the gravel road the ridge exposes Santa Elena Limestone, Del Rio Clay, and is capped by Buda Limestone.

85.0 1.6 The Christmas Mtns Tertiary intrusive complex shows on the skyline ahead.

85.2 0.2 Highway sign reads "Pack Saddle Mountain, elevation 4661 feet." (4661 ft = 1421 m). Pack Saddle and Panther mtns are both trap-door intrusions, with trap-doors of Santa Elena Fm, raised, in part, to a vertical position by Tertiary mafic plugs.

87.0 1.8 Highway sign reads "Hen Egg Mountain, elevation 5002 feet." The souhternmost exposures identified with some certainty as Devil's Graveyard Fm sit just south and southeast of Hen Egg Mtn.

89.1	2.1	Highway bridge over Adobe Walls Draw. Hen Egg Mtn, a rhyolitic plug, at 4:30, Panther Mtn at 10:30, and Pack Saddle at 11:00. Hills in the near foreground to the west are lower limestones of the Boquillas Fm. To the east (left) Pen Fm is exposed.
91.8	2.7	Mor Tertiary intrusions (riebeckite rhyolite) of the Christmas Mountains complex, into Pen Fm.
93.5	1.7	Hen Egg Mtn at 4:00.
94.5	1.0	Wild Horse Mesa to the left.
96.0	1.5	Various Tertiary intrusions of the Christmas Mts, intruding Pen Fm.
97.5	1.5	Willow Mtn, notice the exceptional columnar jointing, on the left.
99.2	1.7	Bee Mtn to the immediate right, a mafic Tertiary intrusion has brought up small blocks of Cretaceous limestones as "inclusions."
99.9	0.7	Study Butte "Y", intersection of TX 118 and FM 170. Turn west (right) on 170. Notice the new motel to the left. It is built on Gulfian Pen Fm (clay) with no foundation. As we travel from here to Lajitas, we will be travelling along the Terlingua Zone.

The road log along FM 170 is the same (except for assumed direction of travel) as for the first 16.9 mi (27.3 km) of the day 2 road log.

END OF DAY 1 ROAD LOG

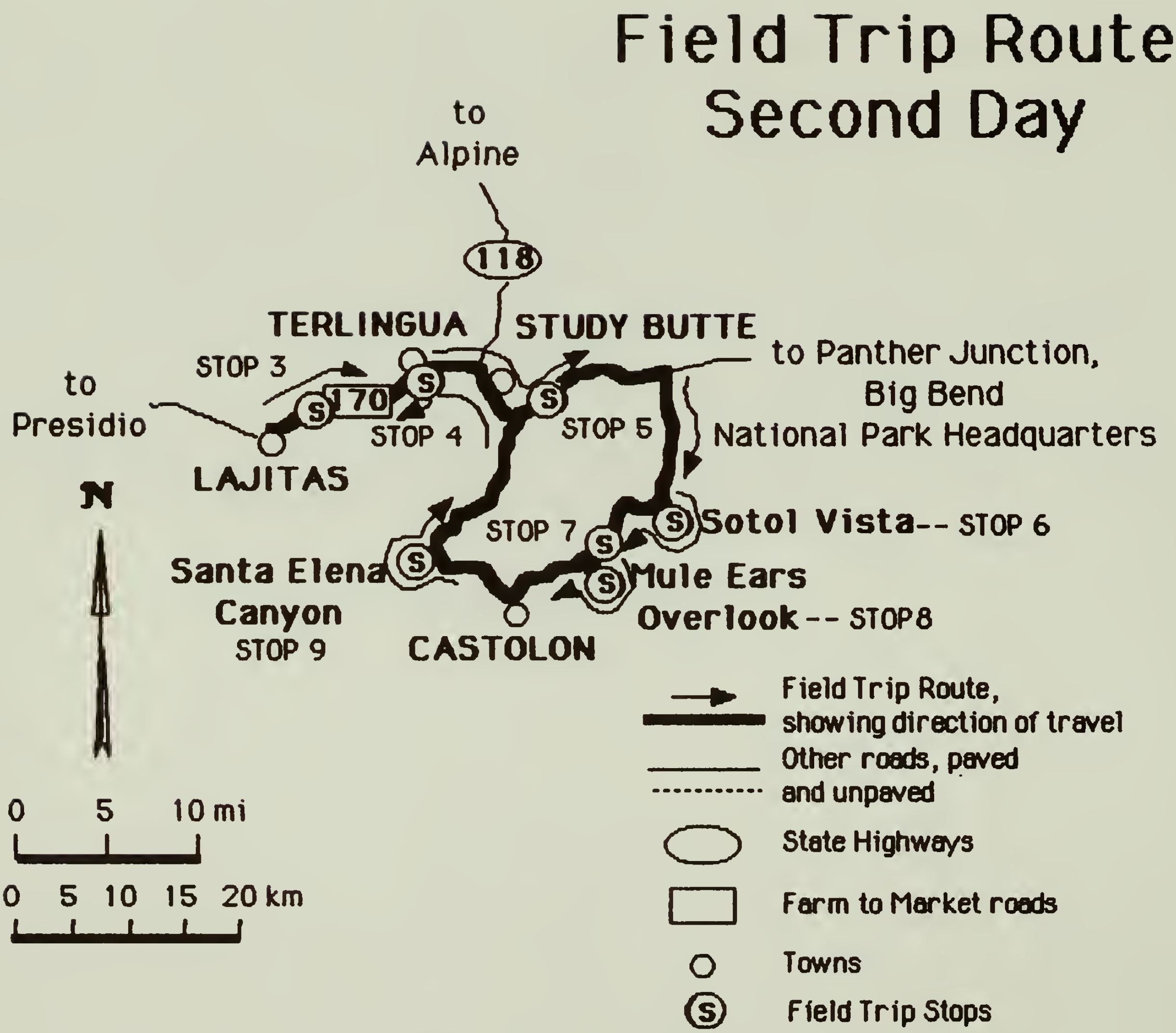

Field Trip Route
Second Day
to
Alpine
118
TERLINGUA
STUDY BUTTE
to Panther Junction,
Big Bend
National Park Headquarters
to
Presidio
STOP 3
170
STOP 4
STOP 5
LAJITAS
N
Sotol Vista-- STOP 6
STOP 7
Santa Elena
Canyon
STOP 9
Mule Ears
Overlook -- STOP8
CASTOLON
0 5 10 mi
0 5 10 15 20 km
Field Trip Route,
showing direction of travel
Other roads, paved
and unpaved
State Highways
Farm to Market roads
Towns
Field Trip Stops

FIGURE 7

ROAD LOG, DAY 2

FROM LAJITAS, EAST ALONG FM 170 TO INTERSECTION WITH TEXAS 118, SOUTHEAST THROUGH STUDY BUTTE, TO BIG BEND NATIONAL PARK, AND TO SANTA ELENA CANYON (by way of ROSS MAXWELL DRIVE).

(Figure 7)

0.0 0.0 Start, Cavalry Post Motel parking lot, Lajitas, elevation 2342 ft. (714 m). According to Maxwell (in Maxwell and Dietrich, 1965) the name Lajitas means "the flat, or flaggy, rocks," and would presumably have reference to the considerable exposures of San Vicente Mbr (yellow thin-bedded limestone monotonously interbedded with thin layers of limey shale), Boquillas Fm, widely exposed in the immediate neighborhood. The broken northern end of Mesa de Anguila lies to the south; the Rio Grande is to the southwest, and enters Santa Elena Canyon about two miles (3.2 km) from here; condominiums are ranged in the foreground to the west, South Lajitas Mesa is to the northwest, and Lajitas Mesa to the north. One might say that the term "mesa'is used a bit casually in this area.

Lower Cretaceous Santa Elena (resistant darker grey limestone), Del Rio (brown shale) and Buda (ledge forming thin "white" limestone) are well exposed to the south across the Rio Grande where the northwestern end of the Terlingua Fault Zone, boundary of Mesa de Anguila, curves westward and dies into an approximately east-west lineation (Terlingua Zone) in which Lajitas sits. Lower Tertiary clays, volcaniclastic sedimentary rocks and volcanic flows (notably, Alamo Creek (?) near the base, Bee Mtn, and at the top, Tule Mtn mbrs) of the Chisos Fm are exposed to the northwest and north, resting on Upper Cretaceous Javelina Fm (South Lajitas Mesa) or the older Boquillas Fm (Lajitas Mesa) (McKnight, 1970). The query appended to the Alamo Creek Mbr above arises from the fact that very similar flows in a virtually similar stratigraphic situation near Hen Egg Mtn have yielded dates of 47 - 52 ma, too old for the reasonably well established 42 ma age of the Alamo Creek Mbr. South Lajitas Mesa is notable for having at the top, the southeastern-most exposures of the 32 ma Mitchell Mesa Rhyolite, believed to have been deposited by an ignimbritic eruption possibly fro Chinati Caldera

roughly 85 mi (137 km) away (Cepeda, and Henry, 1983).

0.3 0.3 Lajitas Airport, and adjacent exposures of San Vicente Mbr, Boquillas Fm; Lajitas Mesa to the north.

1.2 0.9 At the north end of the airstrip, on the northeastern skyline, is Tres Cuevas Mtn at 11:00 (the three caves are on the Northwest face), Black Mesa at 10:00 (both held up by the Santa Elena Fm), and to the east at 11:30-12:00 the white peak is California Hill (capped by Buda Fm), part of a broken ridge called the Sierra de Cal. Black Mesa sits atop the Terlingua Uplift; Tres Cuevas Mtn and Sierra de Cal are surface expressions of the high side of the Terlingua Monocline, marginal, in part, to the Terlingua Uplift. The road climbing up the face of Tres Cuevas Mtn goes to the Lone Star and Mariposa (mercury) mines, and a branch runs over to and beyond Black Mesa.

1.6 0.4 Dirt road to the left goes to the Fresno Mine, the western-most producing mine in the Terlingua Mining District.

2.1 0.5 Stop 3. Good view of Black Mesa at 10:00, Tres Cuevas Mountin at 11:00, and California Hill at 11:30-12:00. To the south-southwest, from 2:30-4:00 is Mesa de Anguila, a block of Lower Cretaceous rocks upthrown along the Terlingua Fault Zone. The Chisos Mountains are in the far distance at 2:00, and the Reed Plateau, along the bend of the Terlingua Monocline, is at 1:00.

We are on the southwest side of the Sunken Block defined by Udden in 1907, and at the northwest corner of the most deeply sunken part of that structure (the Delaho Sub-block of the Park Block). Structural relief in from Black Mesa out into the Delaho Sub-block is on the order of 5000 ft (1524 m). Most of this relief is the result of mid to late Teriary and Quaternary deformation.

The Sunken Block is itself rhombic, with distinct northwest-southeast boundaries, and less distinct east-west boundaries. Its east-west dimension is about 50 mi (81 km), and it extends at least 60 mi (97 km) to the northeast of us as a recognizable later Cenozoic feature, and more than that to the southeast.

We are standing at the base of the Terlingua Monocline, at approximately the point where it changes its trend from

northwest-southeast along the southwest side of the essentially rhombic Terlingua Uplift to east-west along the Terlingua zone, not to be confused with the Terlingua Fault Zone, which is south of us. Apparently geologists have long noticed the name Terlingua, probably because it has been on more maps than anything else in the neighborhood.

Black Mesa appears to be a plug of Commanchean rocks (Santa Elena Fm) as nearly cylindrical as the joint pattern would permit, that was forced up, presumably by an unexposed intrusion. Subsequently, rhyolitic volcanism produced collapse of the northwest quadrant of the uplift, to produce Lowes Valley. Lowes Valley has a floor that exposes a megabreccia of Comanchean, Gulfian, and Tertiary rocks, and a small rhyolite intrusion dated at about 24 ma. The nature, and origin of the megabreccia in Lowes Valley help to show that the Terlingua Uplift is a comparatively young structure, no older than mid-Tertiary. This is a useful idea because a major Late Eocene river flowed across this area, on a Gulfian terrain, mainly on Boquillas and Aguja fms; the uplift would have been very much in the way.

Tres Cuevas Mtn is an anticline whose axis cuts across the northwest axial trend of open, low amplitude Laramide folds; its north-northeastern limb is broken by a reverse fault. There are similar structures northwest of it. At the foot of the mountain, where basal Ernst Mbr, Boquillas Fm, would be expected to be exposed along this part of the Terlingua Monocline it is not present. Whether its absence is stratigraphic or structural causes is a problem that remains to be solved. Structures at Tres Cuevas Mtn may be related to structures that we will see at Stop 4, and small structures in southeast of there, and in The Reed Plateau. Although many of the structural features that Keith and Barrett (1976) suggest for a monoclinal situation can be observed, I do not think that all aspects of the apparent deformation of the Terlingua Monocline can be explained by their stress model.

From here to the Park entrance, we will travel along the complex Terlingua Monocline. Beyond Study Butte, we will cut across the northeastern corner of the Delaho sub-block, and travel a short

distance down its east-northeastern side.

3.5 1.4 The plutonic core of the Chisos Mts, at 11:00-12:00 in Big Bend National Park, is facing us, but the highest point, Emory Pk, is capped by rhyolite of the roughly 30 ma Burro Mesa Mbr of the South Rim Fm, the unit that overlies the Chisos Fm. Pine Canyon Caldera, into and from which the South Rim Fm was erupted sits at the northeast (left) corner of the Chisos Mts block as viewed from here. Sierra Aguja is to the right at 1:00, with Mesa de Anguila to the right in the distance.

4.6 1.1 Croesus Canyon to the left, separating Tres Cuevas Mountain and Sierra de Cal, is a deep cleft following a joint trend in the Santa Elena Fm.

6.5 1.9 Flat-irons of Buda Formation, at 8:00-10:00, are upturned along the Terlingua Monocline. The Reed Plateau, a relatively small block which forms the southern tip of the Terlingua Uplift is seen at 1:00-2:00. The northwest corner of The Reed Plateau marks the point where the Terlingua Monocline turns abruptly to the southeast. To the south at 3:30-6:00 there is a good view of the fault-line scarp of the principal fault in the Terlingua Fault Zone.

8.4 1.9 The road crosses Well Creek; Well Creek Graben, left at 8:00, is a small rhomb graben.

8.7 0.3 The road crosses bend of Terlingua Monocline.

8.9 0.2 Buda Limestone, uppermost formation in the Comanchean Series, capping a hill; and grey-brown shale of the Del Rio Fm, in road cuts and hill slopes.

9.3 0.4 Santa Elena Limestone exposed in the road cut; this is the site of the Little 38 Mine, of which only minor traces remain today.

9.4 0.1 Road tops crest of 38 Hill; The Long Draw Graben, northeastern boundary of the Terlingua Uplift, lies before us with exposures of Pen Fm (grey and yellow shale), in fault contact with the San Vicente Mbr, Boquillas Fm, on each side; the northwestern end of The Reed Plateau is on the right.

10.4 1.0 Ahead, FM 170 crosses Long Draw Graben. At about this point, the graben as seen to the southeast, has a generally northwest-southeast trend, but abruptly takes a more northerly trend to the north-northwest. To the left at the arroyo crossing is a small

mafic intrusion; Santa Elena Fm siliceous limestone markes the fault line scarp to the right.

11.1 0.7 Second crossing of The Long Draw; down faulted Pen Fm to the left, relatively uplifted San Vicente mbr, Boquillas Fm, to the right.

11.2 0.1 Rainbow Mine, part of the Chisos Mine complex at 7:00, Chisos Mine (tailings) at 9:00. Major early mercury production in the 1890's was from the Mariposa mine to the west, but the Chisos Mine, principal support for the town of Terlingua in the period from the First World War to about 1943, far outstriped the declining Mariposa mine. Chisos Mountains in the distance at 11:30.

To the right at 1:00-2:00 are good examples of ramping tear faults involving Santa Elena Fm, suggestive of right lateral fault motion, in good agreement with the apparent rotation of The Reed Plateau and the series of very small blocks to the east of it, including the one we stand on. At a larger scale, the system in which they developed appears left lateral, and the overall system may have been right lateral. Associated with the rotation is evidence of compression diagonally across these small blocks, which may fit with the structures modifying the Terlingua Monocline at Tres Cuevas Mtn. These features could fit reasonably well with an overall right lateral system, but not, it seems to me, with extension. Because I regard these structures as young, it is necessary to place them in a time of transition from earlier left transpression to the later and modern regime of right transtension. Most of the structural relief in the area is the result of right transtension that have been dominant for the last 20 ma.

11.4 0.2 Third crossing of The Long Draw.

12.1 0.7 The road climbs over flexure of the Terlingua Monocline, northwest side of The Long Draw Graben; exposures are again San Vicente Mbr, Boquillas Fm.

12.4 0.3 Stop 4, short walk. Terlingua townsite is about one half mile (0.8 km) to the left, northwest of FM 170.

This stop is located at the southwest edge of a horst of San Vicente Mbr, Boquillas Fm, bounded to the west by a sheared (right lateral motion) monocline bent down into the Long Draw Graben, and to the east by high angle faults that step down into the Cigar

Mountain Graben. Across The Long Draw sits another horst, The Reed Plateau, with, in many respects, a very similar structural situation: high angle faults on the northeast side, and a monocline on the southwest side. Both horst blocks show clear evidence of diagonally directed compression. The main flexure of the Terlingua Monocline is south of us, bent around these two blocks. Along a line from just north of our present position, back to 38 Hill, The Long Draw changes abruptly from its west-northwesterly trend to a northwesterly trend.

12.6 0.2 Cigar Mtn (analcime-bearing hawaiite intrusion) at 12:00, Saw Mill Mtn (trachyte intrusion) at 9:00, Hen Egg Mtn at 10:00, and Panther Mtn is at 11:00.

13.5 0.9 Gravel road to the left is an old county road which runs about 2 mi (3.2 km) up the Cigar Mtn Graben, before turning northeast across Terlingua Creek. Although it eventually reaches TX 118, maintenance beyond the creek is infrequent, and the road can be dangerous. In the late '70's, until legal difficulties about land ownership intervened, lignite from the Maestrichtian Javelina Fm just northwest of Leon Mtn was mined as a drilling mud additive.

14.0 0.5 Terlingua air strip to the right; the faulted boundary of the Cigar Mtn. Graben runs doen the east side of the airstrip but is covered here by pediment gravel.

14.8 0.8 Bee Mtn at 12:00; notice the columnar jointing of this middle Tertiary intrusion. Willow Mtn at 11:00, has spectacularly well developed columnar jointing; beyond and to the right, is Santa Elena limestone dipping off of the southern limb of the Christmas Mountains Anticline. The northern limb is less impressive, and the structure is much like a monocline.

15.1 0.3 Maverick Mtn at 12:00, Study Butte below the mountains, Chisos Mtns in the distance, 248 Mine and abode ruins in the near distance to the left. The mineralizing fluids that emplaced the mercury in the Terlingua Mining District flushed hydrocarbons from the Boquillas Fm, and in some places concentrated heavy asphaltic residue with the cinnabar. The 248 Mine had the dubious distinction of working about the worst of these asphaltic deposits; "worst" because the asphalt caused severe problems in retorting the ore. The wooden headframe

for the mine stood until about six years ago when it was hit by lightening. The frame burned down, and the mine and its tailings caught fire; the surface fire quickly went out, but the mine continued to burn underground for over two years. The Air Quality Board tried, none too successfully, to assure local residents that the smoke did not contain dangerous amounts of mercury, but it was not until the pavement of FM 170 began to melt and run downhill that anyone got serious about trying to smother the fire. As far as I know, there have been no plumes of smoke for the last two years. This, and various other locations in the area is features prominently in the film "Barbaross" which starred Willie Nelson and Gary Busey.

16.1 1.0 The road (FM 170) crosses Terlingua Creek; on the west side, La Kiva, a notable watering hole built out of large blocks of reddish sandstone from the Aguja Fm, is to the right at Big Bend Trailer Park; Highway Department buildings are to the left.

17.0 0.9 Headquarters for Terlingua Medics, to the right, an expertly run medical aid station providing the only medical care closer than Alpine.

18.3 1.3 Study Butte "Y", intersection of FM 170, and TX 118; Bee Mtn to the north (there is a Bee Mtn in the southwestern part of Big Bend National Park, after which the Bee Mtn Mbr, Chisos Fm is named; this is another Bee Mtn). The yellow and grey low hills in the foreground are formed from somewhat smectitic clays of the thin bedded Coniacian-Santonian Pen Fm. The new motel on the east side of the Texas 118, just east of the intersection is a wood frame structure supported only by cinder blocks resting on the Pen Fm, and should prove an interesting experiment in strength of materials.

19.3 1.0 Bridge over Rough Run Creek, Study Butte. To the east, on the flank of the butte is the Study Butte (mercury) Mine, inactive since the Diamond Shamrock Corporation discontinued operations here in 1972. This, and the Fresno mine at the westend of the East-West Terlingua mining district, were the last two functional mines in the region, and ceased activities the same year.

19.6 0.3 The Study Butte Store (pardon me - Shopping Mall) at the left.

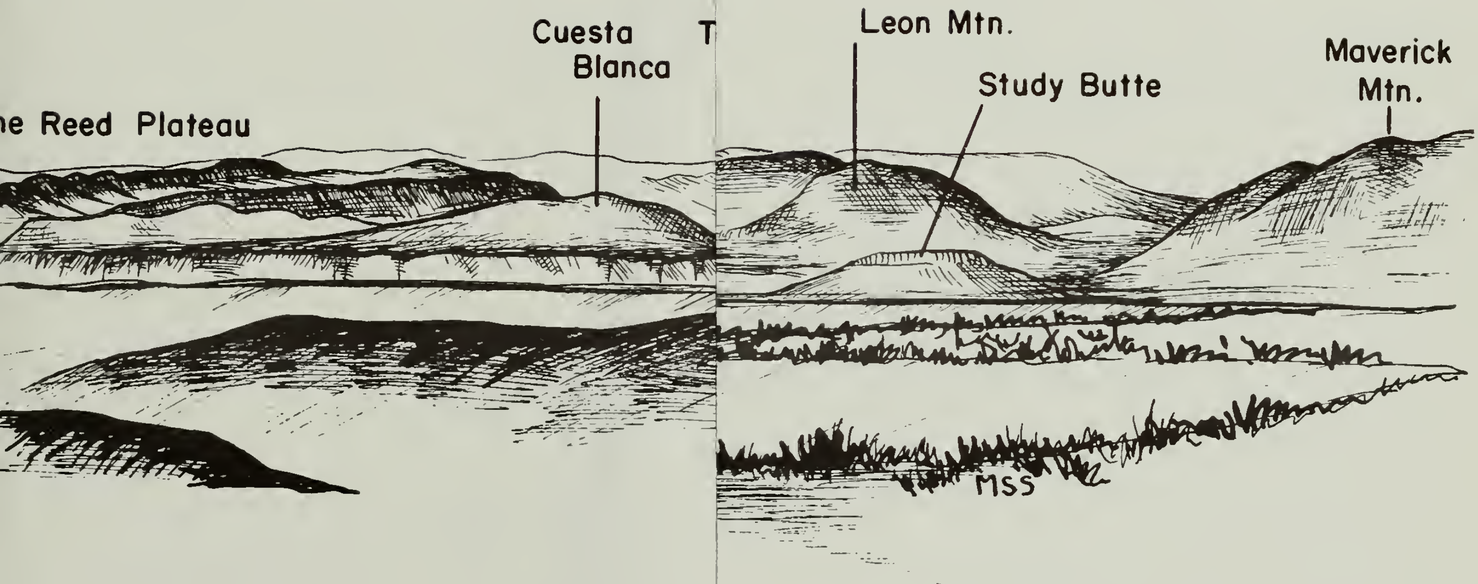
20.7 1.1 Begin crossing the Terlingua Monocline, travelling in the direction of dip; yellow and grey clays in the foreground are the variously weathered Pen Fm.

21.1 0.4 Entrance to Big Bend National Park, elevation about 2200 feet; although there is some structural complication, as we go from the entrance to the base of the first hill where the road climbs to the lowest major pediment, we will be going in the direction of dip across the Terlingua Monocline, from Pen Fm (we have been driving in its unit since just before we turned southeast onto Highway 118), though the Aguja Fm, and into the more colourful Javelina Fm. From physical stratigrapher's point of view, the contacts of these formations are gradational.

22.3 1.2 Gravel road, to right (west), to Santa Elena Canyon; we will return by this route this evening.

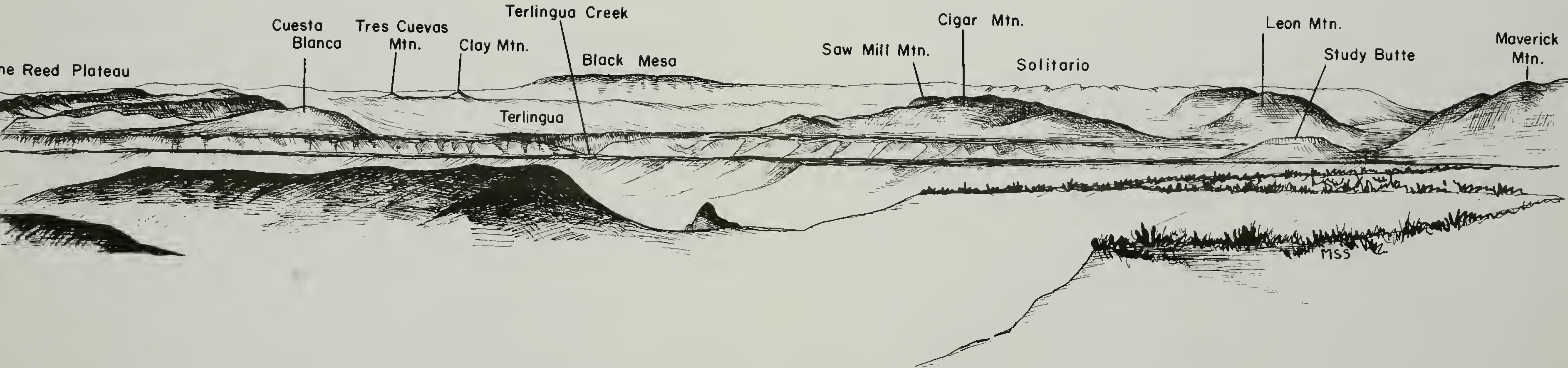
22.8 0.5 Day of the Dinosaurs exhibit turn-off, Stop 5. The view northwest (Fig 8) is into the Painted Desert (Dawson Creek is the near drainage, while Rough Run Creek is the larger drainage to the north). The exposed rocks are colorful, tilted Javelina, and yellow Campanian-Maestrichtian (?) Aguja fms on the limb of the Terlingua Monocline. The structure is not identifiable much to the east. Maverick Mtn, elevation 3496 ft (1066 m), to north-northwest is a lacolith of sodic trachyte. Terlingua townsite lies to the northwest with the Terlingua uplift west of it, and the rim of the Solitario (which sits at the northwest end of the Terlingua Uplift) forms the skyline behind it. To the southwest and south (Fig 9) Santa Elena canyon is cut through Lower Cretaceous limestones upthrown along the Terlinqua Fault Zone; the block north of the canyon is the Mesa de Anguila; that to the south, in Mexico, is the Sierra Ponce. Tule Mtn (flat topped mountain) is the south southeast, Burro Mesa to the east, behind which are the Chisos Mountains.

23.9 1.1 Mule Ears Pks to south, Tule Mtn at 2:00 (flat top of Tule Mtn Mbr tilted to the east), and Burro Mesa, elevation 4,000 ft (1,229 m), to the east. Tule Mtn Mbr (trachyandesite flows, primarily, but including some that are most mafic) is one of the widest spread and most prominent of the members of the Chisos Fm, and occurs on the



Cuesta Blanca
T
Leon Mtn.
Maverick Mtn.
Study Butte
ne Reed Plateau
MSS

FIGUR



Terlingua Creek
Cigar Mtn.
Leon Mtn.
Cuesta
Blanca
Tres Cuevas
Mtn.
Clay Mtn.
Maverick
Mtn.
Saw Mill Mtn.
Study Butte
Black Mesa
Solitario
ne Reed Plateau
Terlingua
MSS

FIGURE 8

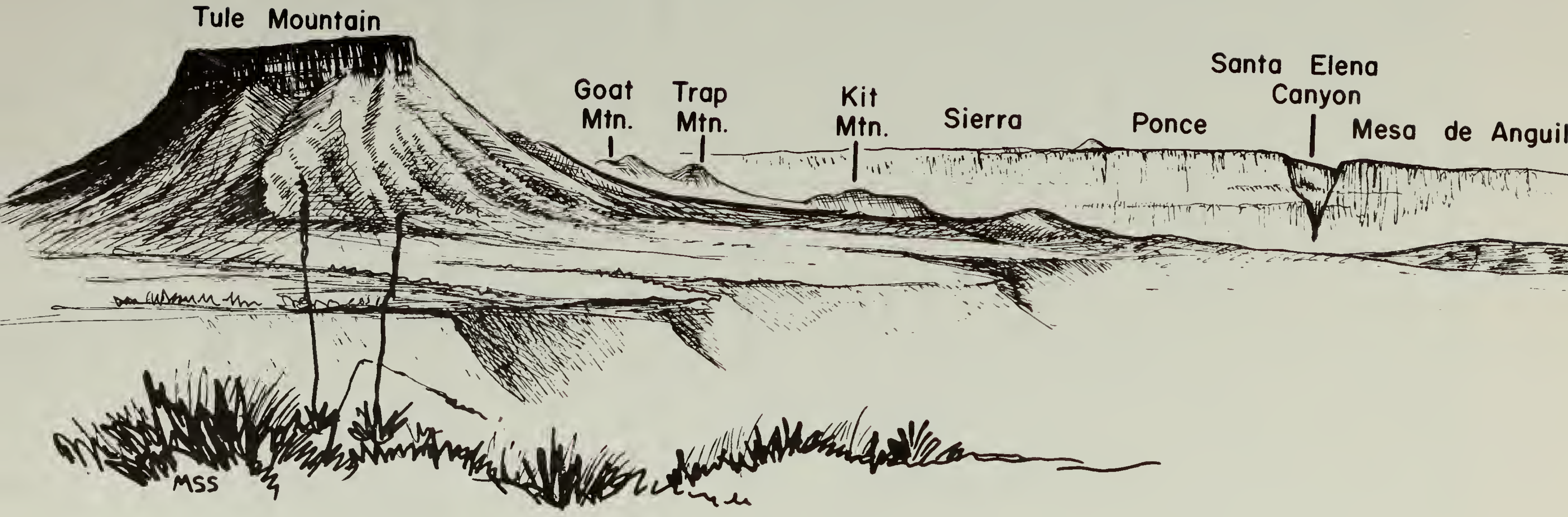

Tule Mountain
Goat Mtn.
Trap Mtn.
Kit Mtn.
Sierra
Ponce
Santa Elena Canyon
Mesa de Anguil
MSS

FIGURE 9

flanks of the Bofecillos Mts near and northwest of Lajitas. Burro Mesa Mbr well exposed at the south end of Burro Mesa, is a thick valley filling rhyolite flow, youngest member of the South Rim Fm, and youngest major volcanic unit of the Chisos Mts volcanic pile.

29.2 5.3 Northern end of Burro Mesa; canyon to northeast, left, is that of Rough Run Creek, cut into Javeline (to the west), and Aguja (to the east) fms. As we come around the end of Burro Mesa, the road turns to the south for about a mile; in this stretch, we are travelling on the hanging wall of, and just west of, the trace of a major fault in the Burro Mesa Fault Zone. The Burro Mesa Fault Zone is a partial compliment to the Terlingua Fault Zone; the two zones define a broad, complex graben (the Delaho sub-block) that is structurally, the lowest part of the Park Block, a portion of the "Sunken Block" (Udden, 1907), in which nearly all of Big Bend National Park sits. The main mass of the Chisos Mountains sits atop a broad horst (the Chisos sub-block), and there is another major complex graben (the Estufa sub-block) on the northeast side of the Park.

30.1 0.9 Cottonwood Creek.

30.5 0.4 Turn right onto Ross Maxwell Appreciation Scenic Drive, to Sotol Vista, Castolon, and Santa Elene Canyon; Burro Mesa forms the skyline on thes west.

32.5 2.0 Roadside overlook; to the east (left, about 10:00), is a good view of the Window, through which The Chisos Mountains Basin, drains; Casa Grande behind.

33.9 1.4 Exhibit to west, Old Neville Ranch below Burro Mesa rim; Javelina Fm exposed, as we are travelling on the foot-wall of the fault in the Burro Mesa Fault zone.

34.7 0.8 Road side exhibit at two rhyolite porphyry (trachyte ?) dikes, part of a set, younger than the Chisos Fm at least, possibly controlled by the general trend of the Burro Mesa Fault Zone, but here at a fairly small angle across the trend of younger (?) faults.

36.3 1.6 To the southeast (left, at 10:00), drag on two faults in the Burro Mesa Fault Zone has produced a small synformal graben in sedimentary rocks of the Goat Mtn mbr of the Chisos Fm; Chisos Mountains pluton (further left) at 8:00.

37.6 1.3 The road crosses another rhyolite porphyry dike; bridge; we follow the fault-line valley between the Chisos Mts and the obsequent fault-line scarp; Burro Mesa to the right is down relative Chisos Fm to the left.

38.8 1.2 Road side exhibit overlooking Sam Nail (or Wilson, or Blue Creek) Ranch.

39.0 0.2 Scenic loop to Sotol Vista to the left, turn left to the overlook. Stop 6. To the southwest is Goat Mtn, to the northwest is the Solitario rim, to the north-northwest is Burro Mesa, to the north are the Christmas Mountains, to the northeast is the Chisos Mountains Pluton and uplifted Chisos Fm.

Sotol Vista has a particularly spectacular view; much of the gology that we have seen, and will see, is dramatically laid out here. Return to the Park Road, turn left and proceed down hill. From later Eocene time through the earlier Miocene, at least, the Delaho sub-block which we can survey from this point, was persistently low, and accumulated the sediments and volcanic rocks of the Chisos and South Rim fms, and later, the fanglomerates of the Delaho Fm.

41.5 2.5 Hairpin curves take us down through the Fingers Fm, an earlier Pleistocene (?) proximal fanglomerate that developed before the integration of the modern Rio Grande drainage. This unit, and others like it on the northeast and eastern sides of the Chisos Mountains once nearly buried these mountains. Later the Chisos sub-block was uplifted relatively and partially pedimented in the early stages of development of the Rio Grande.

41.8 0.3 Contact of Pleistocene Fingers Fm with the Eocene-Oligocene Chisos Fm. Much of the colorful sedimentary rock, and most of volcanic rocks (exceptions: Wasp Spring (ash flow breccia), Burro Mesa (Rhyolite), mbrs of the Oligocene South Rim Fm) that we will see between here and Castolon belong to the Chisos Fm. The oldest member of the Chisos Fm is a set of "basalt" flows (Alamo Creek) particularly widespread, west and northwest of the Chisos Mts. Apparently reliable dates for this unit average about 42 ma. Tule Mtn Mbr (trachyandesite, with, according to Carman et al (1975), some flows approaching benmoreite composition) has no satisfactory

date, but its age is probably later Early Oligocene, less than 33 ma. The sediments of the Chisos Fm (Goat Mtn mbr, mainly) are fluvial, mainly volcaniclastic, but not entirely of local derivation. The source of many of the conglomerates appears to be to the west. John A. Wilson, after an enormous amount of searching, found a few Uintan vertebrate fossils in the Goat Mtn mbr. The Chisos Fm has been recognized in the Bofecillos Mtns (near Lajitas, among other places) where its base is a bit older than the Canoe Fm in the Park. Similar sediments are much more widespread in this part of Texas. The Devil's Graveyard Fm, an approximate lateral (northern) equivalent of the Canoe and Chisos fms, is a named example of this; and there are un-named examples to the west in Mexico. The Pruett and Duff fms of the Southern Davis Mts are also in part correlative with the Chisos Fm, and the Decie Fm west of Alpine, and represent contemporaneous volcanism from different sources.

43.0 1.2 The surface on which we are traveling at this point is the youngest, and, on this side of the Park, the most wide spread of the pediment levels. In bygone days, surfaces such as this were routes of travel. and roads used to extend from here to the Chimneys (minor rhyolitic necks; a noteworthy Indian site, with pictographs), Luna's Jacal (which we will pass later in the day), and La Coyota, a small community no longer extant. The modern road to the right leads to Burro Mesa Pouroff.

44.7 1.7 Crossing a fault (Burro Mesa Fault Zone) separating Kitt (right) from Goat Mtn (left). Both mountains have capping Burro Mesa Mbr. From here to approximately Castolon, we will be following the trend of a valley filled by the earlier flows of the South Rim Fm - Wasp Spring Mbr, Lost Mine Mbr (a minor rhyolite flow that did not make it into this area), and the thick Burro Mesa Mbr, which completed the filling of the valley. The valley was subsequently sliced by the faults of this graben, trending nearly at right angles to the valley.

44.9 0.2 Road cut through the thick proximal gravel of the pediment on which we have been travelling.

45.2 0.3 Blue Creek low water crossing.

46.4 1.2 Road side exhibit, Goat Mtn overlook, Stop 7.

Behind the bus, to the northeast, is Goat Mtn (see Fig. 10). The lower part of the mountain is Chisos Formation: Tilted Goat Mtn (informal) mbr constructive volcanic apron sediments, now much zeolitized, are overlain by Bee Mtn (basalt), and Mule Ear Spring (welded ash flow tuff; ignimbrite) mbrs; these in turn are overlain by a thin unit of sedimentary tuffs, and Tule Mtn Mbr (coarsely, sometimes very coarsely porphyritic brown trachyandesite). Doming of the Chisos Mtns area in the early stages of formation of the Pine Canyon Caldera (Ogley, 1979) probably caused rapid development of a rugged erosional topography, later burried by the South Rim Fm. The unconformity cuts through Tule Mtn Mbr to below Mule Ear Springs Mbr. Above the unconformity is the South Rim Fm: Wasp Spring Mbr (poorly welded chartreuse and blue-grey ash flow breccia and minor sedimentary beds) overlain by three thick, columnarly jointed cooling units of Burro Mesa Mbr. The Burro Mesa Mbr is one of the more uniform and easily identifiable units, it is a paisanitic rhyolite (comendite) commonly showing strong flow foliation as a result of the interlamellar concentration of the navy blue to blue green "riebecktie" which contrasts strongly with the pale grey aphyric ground mass. The unit was named "Burro Mesa Riebeckite Rhyolite" by Maxwell and others (1967), but there is now considerable doubt that the mineral that produces the characteristic appearance (paisanitic) of this and several lithologically and chemically similar bodies of rock (mostly intrusive) in the Big Bend region is always, or even usually, riebeckite. Thus, there has arisen a reluctance on the part of many workers, Stevens included, to use the full name of the unit. A younger, but chemically fairly similar rhyolite intrusion cuts through the central part of the Goat Mtn exposure.

To the left at 9:00-11:00 is Kitt Mtn, exposing much the same section, though the Wasp Spring Mbr is much thinner at the near end of the mountain; however, there is another valley in the unconformity between the Chisos and South Rim fms at the northwestern end. Burro Mesa Mbr "riebeckite" rhyolite caps the northwest end of Kitt Mtn. Kitt Mtn is down relative to Goat Mtn.

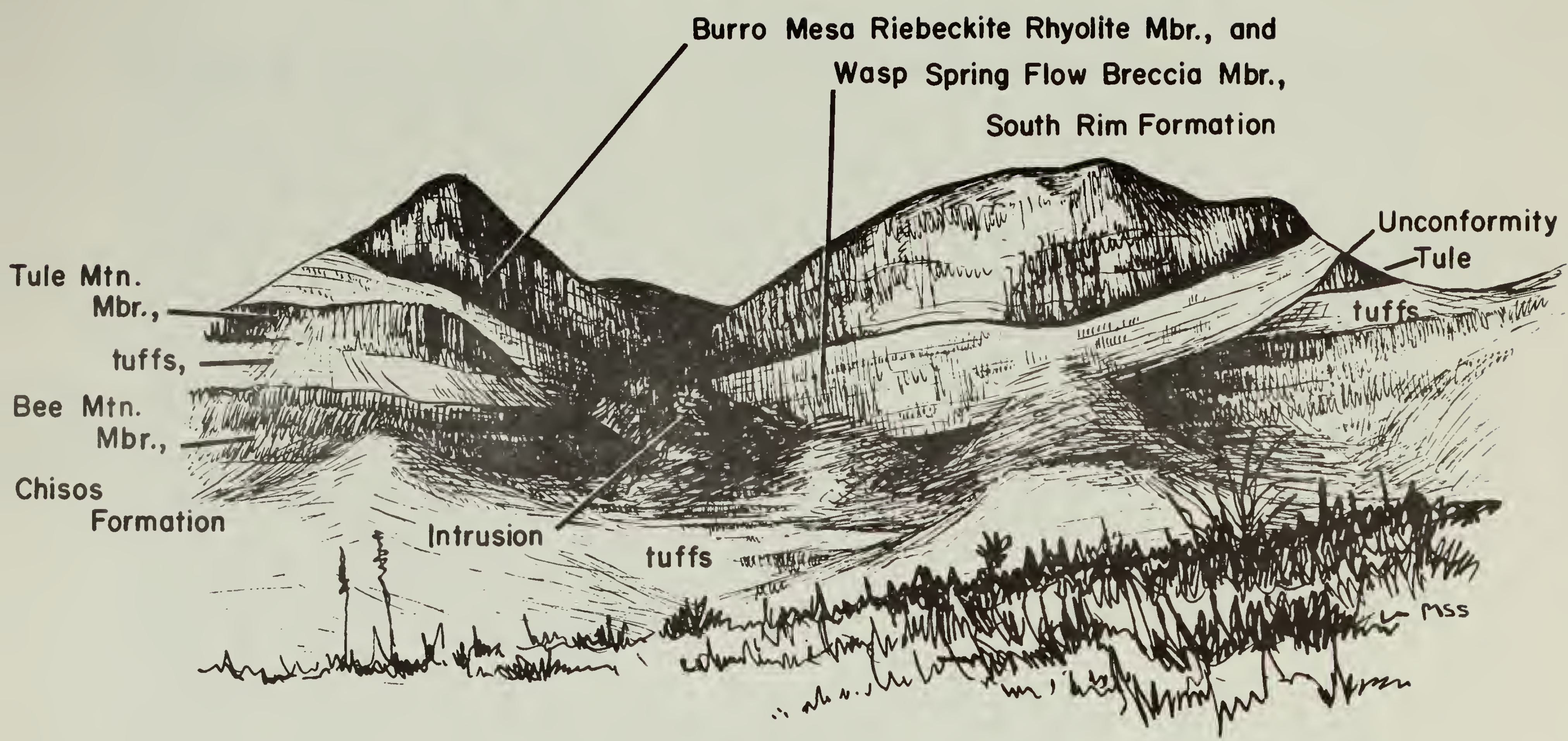

Burro Mesa Riebeckite Rhyolite Mbr., and
Wasp Spring Flow Breccia Mbr.,
South Rim Formation
Unconformity
Tule
tuffs
Tule Mtn. Mbr.,
tuffs,
Bee Mtn. Mbr.,
Chisos Formation
Intrusion
tuffs
MSS

FIGURE 10

47.0 0.6 Mule Ears Peaks Scenic Overlook to the left; turn left.

47. 6 0.6 Mule Ears Peaks Overlook.

Stop 8: The Mule Ears are paired intrusive necks of relatively young "riebeckite" rhyolite; to the southeast is Round Mtn, capped by Burro Mesa Mbr; to the south, tilted Chisos Fm, Bee Mtn Mbr, Tule Mtn Mbr, and Burro Mesa Mbr exposed; Trap Mtn to the north.

48.1 0.5 Return to the main Park Road, turn left, west.

49.0 0.9 Road cut through Alamo Creek Mbr, a late Eocene, ca 42 ma, suite of related (?) alkalic olivine basalt and mugearite flows (Carmon et al, 1975). The query arises from the fact that in a later study, Stewart (1982) was of the opinion that at least seven flows, from two sources, are collectively referred to as "Alamo Creek Basalt".

49.9 0.9 The colorful clays beneath the Alamo Creek Mbr are a part of the latest Cretaceous Javelina Fm; the Canoe Fm is generally absent on this side of the Park. Here the Alamo Creek Mbr and the Javelina Fm are extensively intruded and overlain by a 24 ma (24.3 ± 0.6) "riebeckite" rhyolite, rather similar in hand-specimen to the Mule Ears intrusions, among others. The occurrence of this body of rock appears to be controlled by a major normal fault (down to the southwest that we are about to parallel. The fault juxtaposes Burro Mesa Mbr with the Javelina Fm, and has a stratigraphic throw of roughly 1,800 ft (549 m) in this area.

50.4 0.5 Arroyo crossing.

50.7 0.3 View of Mule Ears Pks and Round Mtn to the south (left).

51.1 0.4 Arroyo crossing; after crossing the arroyo, the road turns northwest to parallel, for about a mile and a half (2.4 km), the fault referred to above. There are road cuts in the basal proximal fanglomerate of the earlies Miocene Delaho Fm, preserved here in a minor, very narrow graben along the major fault. About a mile south of here, near Delaho Spring, there is a thin basaltic flow near the base of the Delaho Fm, dated at 23.3±0.6 ma, which is the youngest dated evidence of volcanic activity in the Park. The date is in excellent agreement with biostratigraphic evidence (Stevens, M.S., et al., 1969; Stevens, M.S., 1977) of earlies Miocene age.

51.6 0.5 Intrusions of the young rhyolite to the north, in Javelina Fm on the upthrown side of the fault along the northeastern side of the narrow

graben.

52.9 0.6 Delaho Fm exposed to the right, at 3:00 (see Fig. 11); Burro Mesa Mbr (slightly) up-thrown to the left at 11:00.

52.9 0.7 Scenic overlook, "Tuff Canyon." Blue Creek has cut a narrow canyon through Wasp Spring Mbr (blue-gray), and across a small graben containing down-dropped Delaho Fm (pink-buff). The prominent peak to the west is Cerro Castellan, sometimes called Castolon Peak; the capping rock, Burro Mesa Mbr, fills a channel cut into the Bee Mtn Mbr at the southwest end, and rests, still unconformably, on valley filling Wasp Spring Mbr at the northeast end.

53.2 0.3 River Road, to the left, an occasionally improved gravel, sand, deep sand, dust, bed rock, or mud, road traversing the southern region of the Park and eventually joining the Panther Junction-Boquillas paved road. Conditions on this road, as with most unpaved roads in the Big Bend country, can range from good (the family car will make it, but check the front end afterward), 4WD required, construction needed (you do the constructing or turn around), and finally, to "where did it go?" This entrance to the River Road is a recent revival of a very old road, necessitated by a severe attack of "where did a segment located next to the Rio Grande below Castolon go?" about ten years ago.

53.8 0.6 At the base of Cerro Castellan, we pass road-cut exposures of fine, pink buff, Early Miocene (ca 23 ma) Delaho Fm. Elsewhere, rock of similar appearance has yielded an abundant vertebrate fauna.

53.9 0.1 The road runs diagonally across another high angle normal fault that has brought Delaho Fm into contact with very pale grey volcaniclastic sedimentary rocks of the Late Eocene Chisos Fm (ahead of you). The fault is down to the northeast, and has a stratigraphic throw of about 1,200 ft (366 m).

54.2 0.3 Exposures of Chisos Fm intruded by two small glassy "riebeckite" (arfvedsonite?) rhyolite necks, locally called "petrified trees;" one of these is illustrated in Fig. 12. The dark rock towering above them is Alamo Creek Mbr, turned nearly on edge, as the "Trap Door" for a small trap-door intrusion of what is probably the same rhyolite. The very pale grey (white, if one is not a color chart addict) bed in the Chisos Fm is, mineralogically a remarkably pure

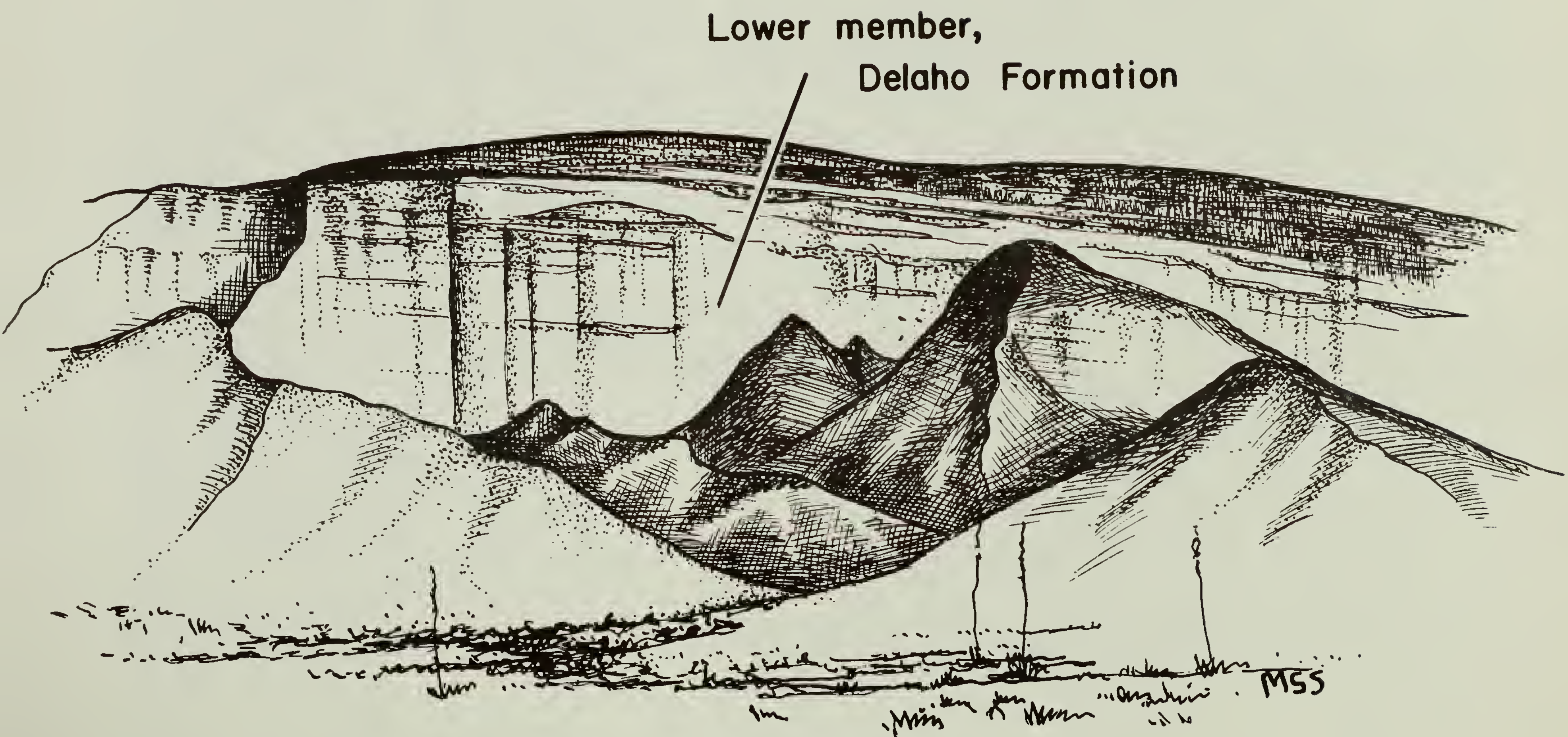


FIGURE 11

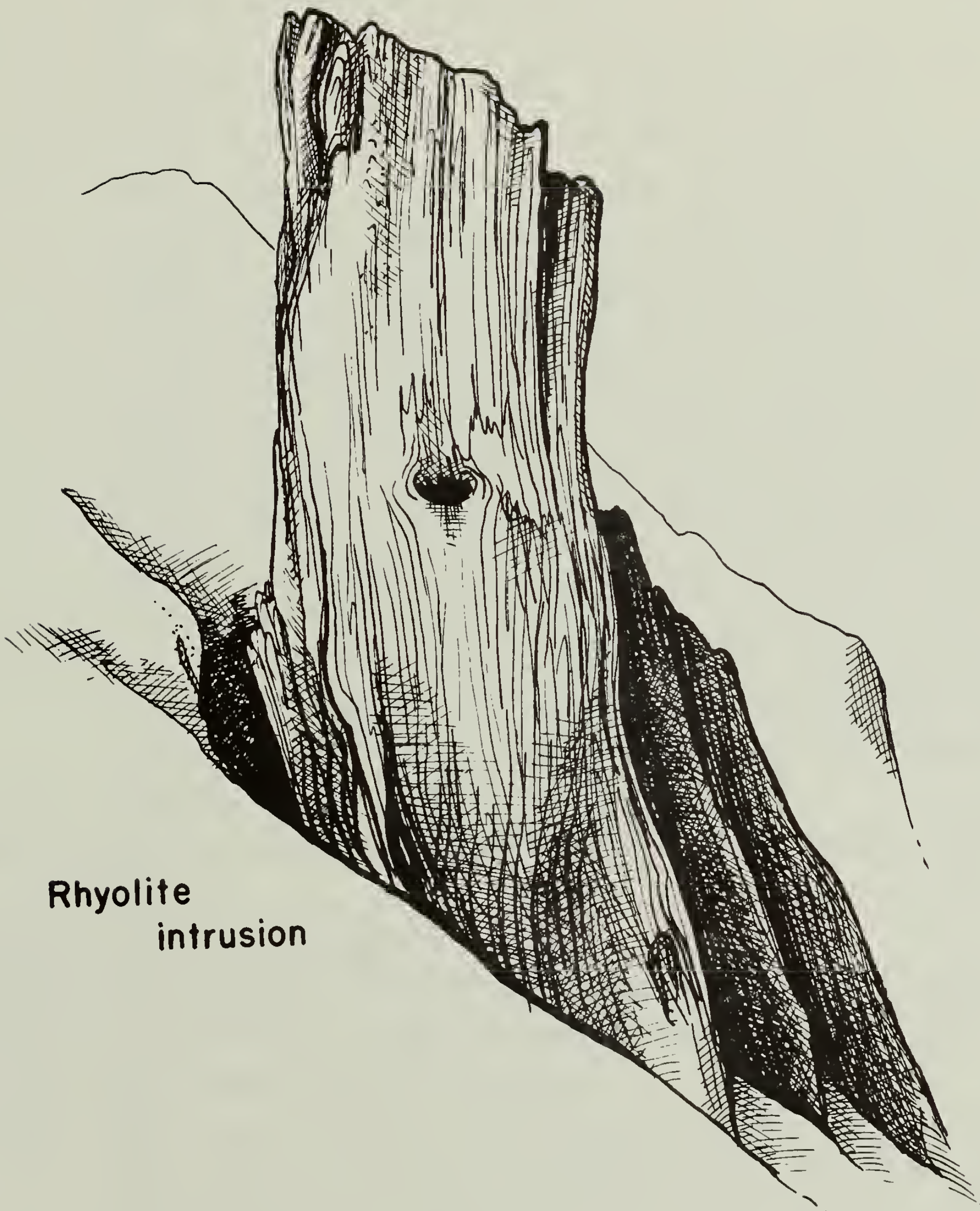


FIGURE 12

deposit of sodic zeolite, clinoptilolite; clinoptilolite is probably the most common diagenetic mineral in this region, though calcite must be nearly as common and smectites are not uncommon.

54.7 0.5 Road cut through Alamo Creek Mbr.

55.1 0.4 Road side exhibit; Cerro Castellan at 8:00, ranger residences to the north, on the pediment surface (right, at 5:00).

55.7 0.6 Gravel road to Castolon historic area, to the left. Castolon (the name sounds to me like a corruption of "Castellan") is one of the several cavalry posts along the border in this region, at which President Harry Truman is supposed to have served just before the United States became involved in the First World War. The purpose of these posts was to protect this part of Texas from the raids of Pancho Villa (or, more probably, loosely connected partisans of his cause), and with the passing of this threat in the Twenties, the Officers Quarters became a trading post, probably very much like the Lajitas Trading Post, still in operation. In 1957 this area became the last major addition to Big Bend National Park.

55.8 0.1 Dirt road to Santa Elena, Mexico, to left, on Recent Rio Grande alluvium of the modern floodplain, sub-Recent Rio Grande gravel terraces to the right, paved road parallels the terraces; continue straight.

56.3 0.5 Road to Cottonwood Campground and mosquito feeding station, to the left.

56.7 0.4 Blue Creek low water crossing.

57.5 0.8 Desert Mountain overlook to the right; continue straight.

58.2 0.7 Ultramafic sill within Cretaceous Aguja Fm to the right.

58.5 0.3 Alamo Creek low water crossing.

58.9 0.4 Good views of Chisos Mtns and Cerro Castellan (Castolon Pk) to the east, and, to the west, the impressive cliff of the Sierra Ponce, Lower Cretaceous limestones on the upthrown side of the Terlingua Fault Zone.

59.1 0.2 Bridge.

62.2 3.1 Turn-off to west (left) goes to the Rio Grande.

62.9 0.7 Rio Grande floodplain to the left, covered with salt cedar, an import from North Africa that has been in this part of the world for centuries, but is still in the process of making substantial changes

in the hydrology.

63.4 0.5 Road continues to parallel sub-Recent Rio Grande terrace gravels to the southeast (right).

63.5 0.1 Santa Elena Canyon overlook.

63.8 0.3 Gravel road (road from Maverick entrance) joins paved road to the right; turn left into the Santa Elena Canyon parking loop; Stop9.

We are at the base of a magnificent exhumed fault line scarp shown in Fig 13. Although we can not see all of it, there is about 1728 ft (527 m) of relief from river level to the top of the Mesa de Anguila (the block on the U.S. side of the canyon), and about 1,500 ft (460 m) near the canyon. In all, Maxwell (Maxwell and Dietrich, 1965) estimated that there are approximately 2,000 ft (602 m) of the principal Comanchean units of the region on display here, though it's a bit difficult to get close to most of them. Figure 14 illustrates the sequence of units. The top bench-forming unit of the canyon is Santa Elena Limestone which is underlain by the less resistant Sue Peaks Limestone; the second bench is Del Carmen Limestone, and it is underlain by softer Telephone Canyon Limestone; the top of the Glen Rose Limestone is about 100 ft (30 m) above the Rio Grande water level. Terlingua Creek, whose headwaters are just south of Alpine, joins the Rio Grande at this place. Terlingua Creek's valley is much more impressive as a valley than the dramatic canyon in which the Rio Grande flows. Many people, viewing this area for the first time, find it difficult to believe that the fairly unimpressive Terlingua Creek formed this valley. Return to the Park paved road then turn north, left on the gravel road which leads to the Maverick entrance of the Park.

64.1 0.3 View of Terlingua Creek to the left. Terlingua Creek joins the Rio Grande at the mouth of Santa Elena Canyon.

66.5 2.4 Side road, left, to Terlingua Abaja, an abandoned farming community; to the northwest (left at 8:30), Sierra Aguja; continue straight.

68.7 2.2 Rattlesnake Mtn to the left; a shallowly intruded (ca 2,300 ft, or 700 m) 263 ft (80 m) thick complex (three phases of injection) sill of mugearite-related analcime-bearing monzonite wiht syenite masses and lamellae that result from in-place differentiation; early

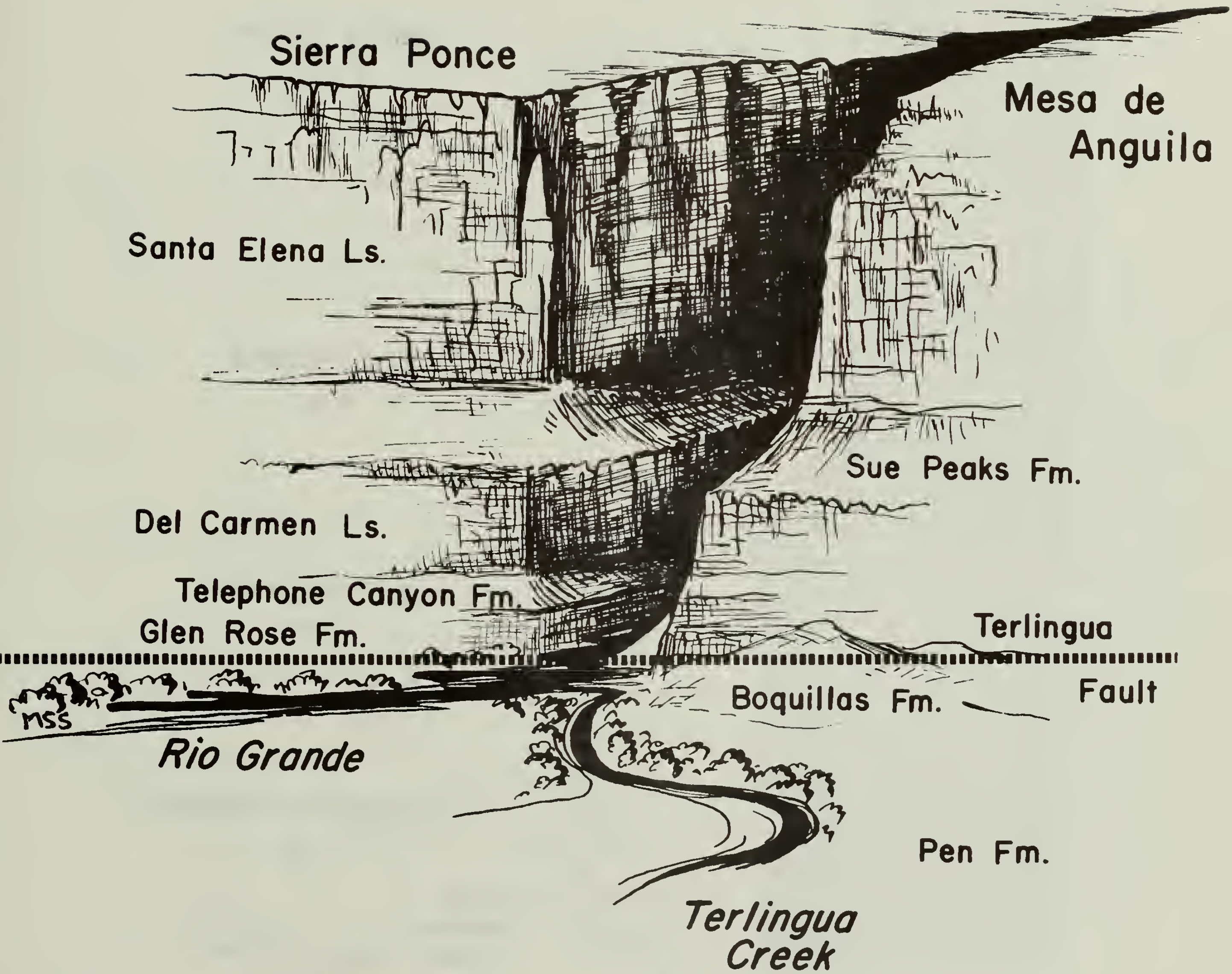
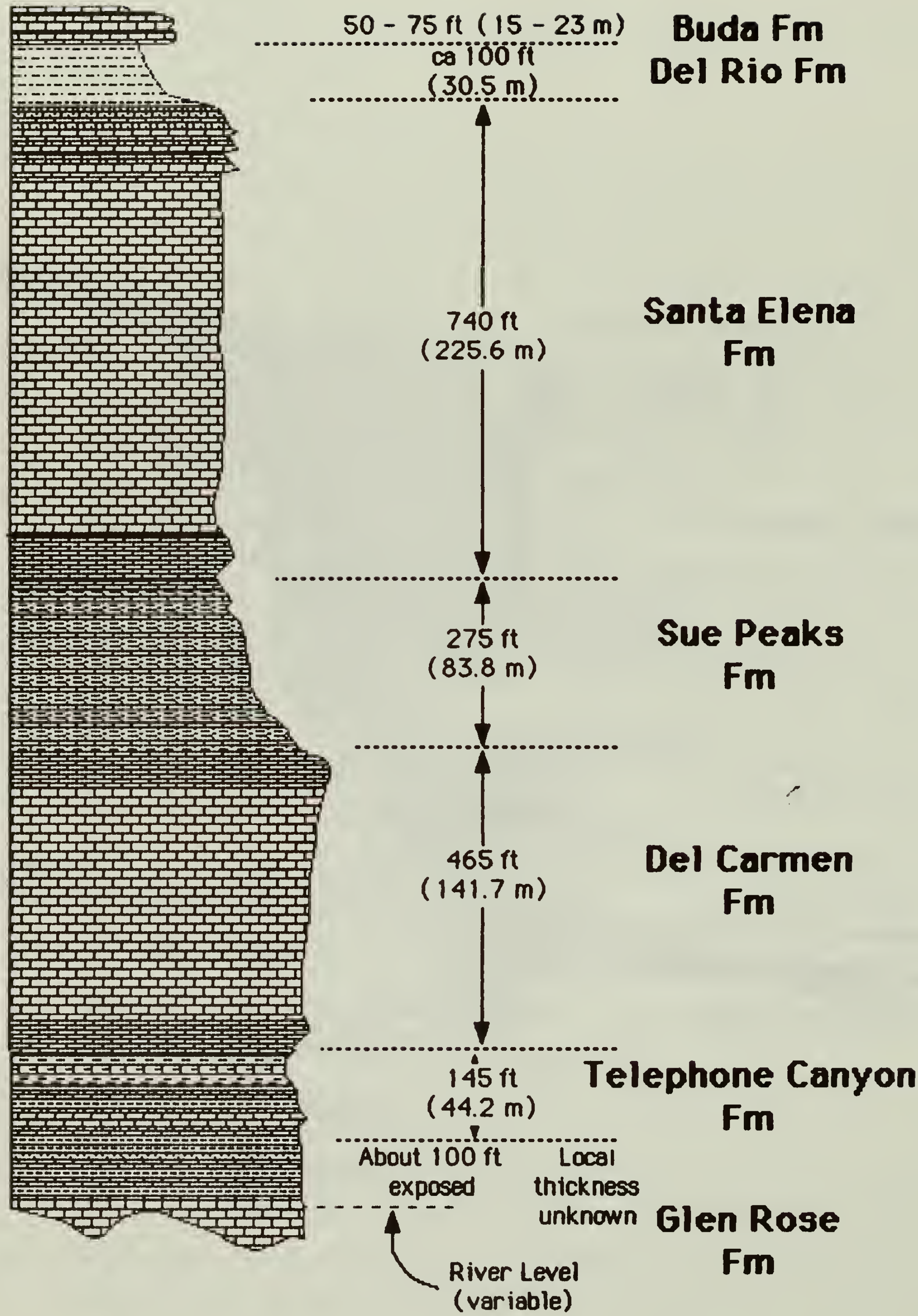

Sierra Ponce
Mesa de Anguila
Santa Elena Ls.
Sue Peaks Fm.
Del Carmen Ls.
Telephone Canyon Fm.
Glen Rose Fm.
Terlingua
Boquillas Fm.
Fault
MSS
Rio Grande
Pen Fm.
Terlingua Creek

FIGURE 13



Stratigraphic Section At Santa Elena Canyon

(Modified From Maxwell And Dietrich, 1965, Fig. 41, P.133.)

FIGURE 14

Tertiary age. "The rocks of the Rattlesnake Mountain sill, as well as others of Big Bend, show distinct chemical similarities to alkalic oceanic suites such as those of the Azores" (Carman et al, 1975).

69.0 0.3 Exposures of tilted Aguja Fm.

69.2 0.2 Second crossing of Alamo Creek low water crossing.

70.0 0.8 Luna's jacal, an abandoned homesite somewhat restored; Senior Luna, several wives and numerous offspring lived here. The jacal is at the base of Pena Mtn which is formed by another silicapoor sill, intruded into Aguja Fm. The Pena Mtn sill is thinner (ca 125 ft, or 38 m) but compositionally similar to the Rattlesnake Mtn sill.

70.4 0.4 Hiking, Chimneys trail, to the right.

70.8 0.4 Third crossing of Alamo Creek.

71.8 0.4 To the east (right, 3:00), across valley, is a fault; Javelina Fm (right), down relative to Aguja Fm (left).

72.4 0.6 Road crosses fault.

72.6 0.2 At same topographic level, Javelina Fm to the right, Aguja Fm to the left.

72.8 0.2 Road cut through relatively thick pediment gravel, near gate; we are climbing back onto the principal pediment surface.

73.4 0.6 Deep valley to the right, exposing Chisos Fm, including dark flows identified by Maxwell (Maxwell et al, 1967, plate II) as Ash Spring Mbr, in fault contact (a minor horst) with Javelina Fm. The change in dips across the valley is the final expression of the Terlingua Monocline, which we are once again approaching.

75.8 2.4 End of the gravel road at Big Bend National Park information center (formerly Maverick Range Station), near the northwest entrance to the Park; turn left, west (and shortly northwest) on the main park road, toward the entrance, and Study Butte; the next stop is Lajitas.

END OF ROAD LOG FOR DAY 2

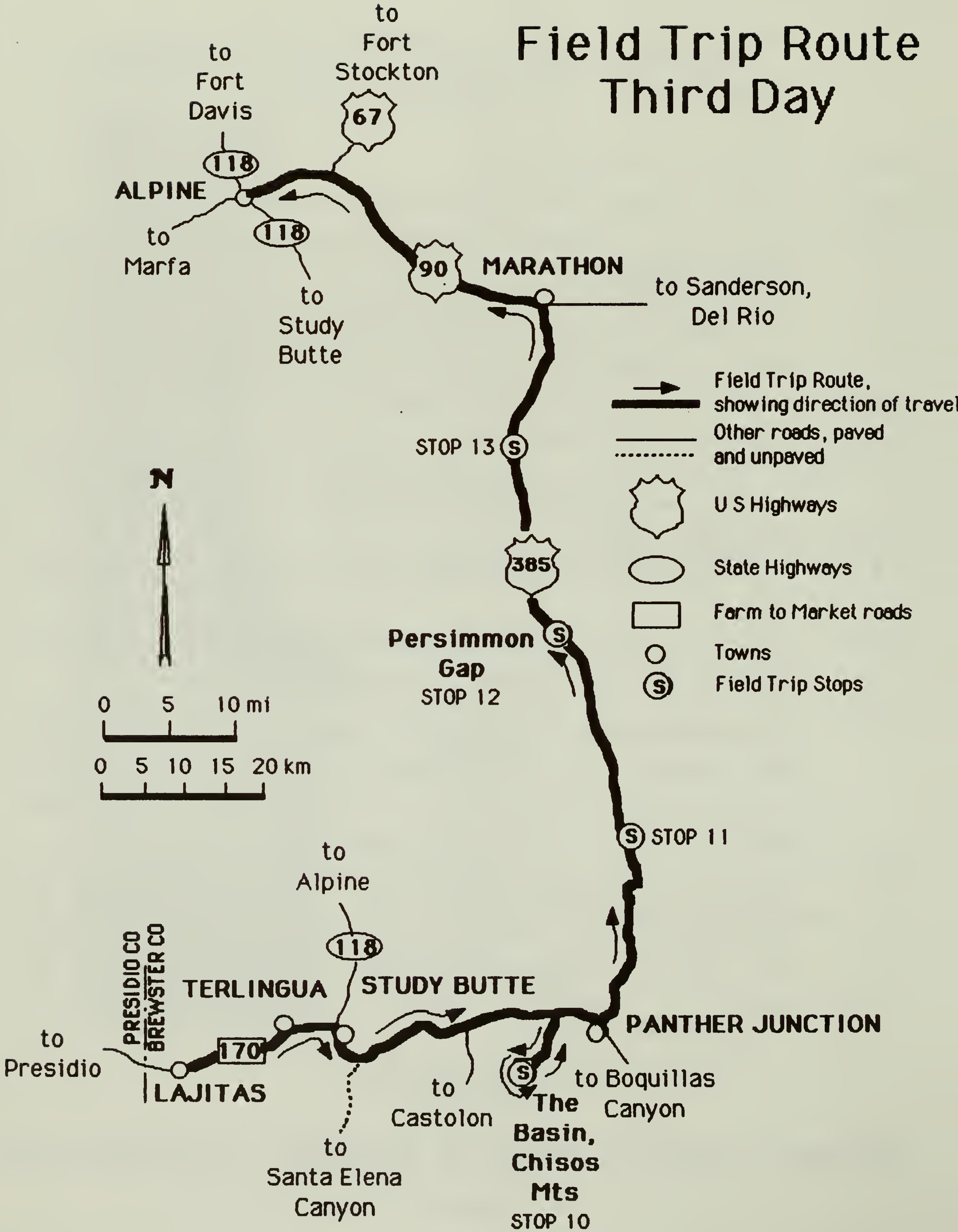

Field Trip Route
Third Day
to
Fort
Stockton
67
to
Fort
Davis
118
ALPINE
to
Marfa
118
to
Study
Butte
90
MARATHON
to Sanderson,
Del Rio
Field Trip Route,
showing direction of travel
Other roads, paved
and unpaved
U S Highways
State Highways
Farm to Market roads
Towns
Field Trip Stops
STOP 13
N
385
Persimmon
Gap
STOP 12
0 5 10 mi
0 5 10 15 20 km
STOP 11
to
Alpine
118
PRESIDIO CO
BREWSTER CO
TERLINGUA
STUDY BUTTE
PANTHER JUNCTION
to
Presidio
170
LAJITAS
to
Santa Elena
Canyon
to
Castolon
The
Basin,
Chisos
Mts
STOP 10
to Boquillas
Canyon

FIGURE 15

ROAD LOG, DAY 3

FROM ROSS MAXWELL DRIVE TO THE CHISOS MTS BASIN, PANTHER JUNCTION, PERSIMMON GAP, MARATHON, AND ALPINE

(Figure 15)

(The Road-Log from Lajitas to the turning for the Ross Maxwell Drive) is the same as for Day 2).

0.0 0.0 Ross Maxwell Appreciation Scenic Drive to Sotol Vista, Castolon, Santa Elena Canyon, to right. Continue straight ahead.

0.6 0.6 Oak Spring Draw (this draw drains The Basin, through The Window); "Sphinx" to the north, left, an erosional remnant of a quartz trachyte intrusion into Aguja Fm; Christmas Mountains, elevation 5735, lie behind, to the northwest.

1.3 0.7 Ash Spring Draw.

2.1 0.8 Sign at roadside, "Croton Peak elevation 4,800 feet;" (4,800 ft = 1,463 m). Croton Pk is formed by the southwestern end of a sheet-like alkalic microgranite intrusion, of which the northeastern end forms the Paint Gap Hills. The gravel road to Croton Springs is 0.2 mi further along.

2.8 0.7 Road cut in Aguja Fm, and the terrane in the foreground is underlain by Aguja and Javelina fms. The Window is seen from about 1:30-3:00; Vernon Bailey Pk, connected by a long northeasterly ridge to Pulliam Pk, occurs to the north, left, and Carter Pk and Ward Mountain are seen to the right, of the Window. All of these mountains are cut from the Chisos Mountains Pluton.

3.2 0.4 Ahead the road climbs a small escarpment called Todd Hill where a major high Pleistocene pediment caps Javelina Fm.

3.8 0.6 Top of Todd Hill, roadcut passes through high Pleistocene fanglomerate.

4.4 0.6 Gravel road to Paint Gap, to left.

4.7 0.3 Draw.

5.6 0.9 Low foreground, at 9:00, to north, columnar-jointed outcrop of quartz microsyenite of the Governement Springs Laccolith which lies, poorly exposed, mainly south of the road here; Pulliam Pk at 2:00 is a part of the approximately 24 ma (recalculated from Daily, 1979) Chisos Mountains Pluton, a microgranite intrusion with irregular

mases of pegmatite.

7.2 1.6 Paved road south (right) up Green Gulch, to The Basin; turn right; Lost Mine Pk is straight ahead after the turn; like the rest of the block of the Chisos Mtns on the east of the road, Lost Mine Pk is carved from the units of the South Rim Fm that filled in the roughly 30 ma Pine Canyon Caldera: Brown Mbr, Lost Mine Mbr (rhyolites), and interlayered tuffs. The South Rim Fm is the last (early Late Oligocene, roughly) major outpouring of lavas in the Park. There is even a bit of Burro Mesa Rhyolite on top of Lost Mine Pk. Pulliam Bluff, and Pulliam Pk, carved from the Chisos Mountains Pluton are n the west.

10.1 2.9 Pulliam Bluff towers immediately to the west; we are entering the eastern part of the Chisos Mountains Pluton.

11.1 1.0 We are well into Green Gulch, surrounded by the Chisos Mountain Pluton, with volcanic rocks of the South Rim Fm forming the high peaks to the east and south.

12.1 1.0 Sharp curve to the right and a steep up-grade; I sincerely hope that the bus can negotiate these.

12.3 0.15 Small parking lot, and entrance to the Lost Mine Trail. Elevation about 5760 ft (1756 m), this is the official high-point of the trip, the highest part of Panther Pass there we enter The Basin. Continue down the twisting descent to the Chisos Mountains Lodge parking lot, at about 5400 ft (1646 m).

13.3 1.0 Road to the right goes down to the Basin Campground.

13.5 0.25 Basin Parking Lot -- Stop 10. This is primarily a stop for a view, and to show you that there are trees and even forests in the Big Bend. Case Grande Pk and The Window are shown in Figs 16 and 17.

19.8 6.3 Back down Green Gulch to the main park road; turn right (east) on the main road.

20.7 0.9 Rosillos Mtns at 9:00, to north. Pedimented badlands at base of Rosillos Mtns are cut in Aguja and Javelina fms.

21.3 0.6 To the south, in the main mass of the Chisos Mtns are, from east (ahead) to west, Pummel, Wright, Panther, Lost Mine peaks; all of these are carved from the South Rim Fm., and together approximate the position of the north rim of the Pine Canyon Caldera from which

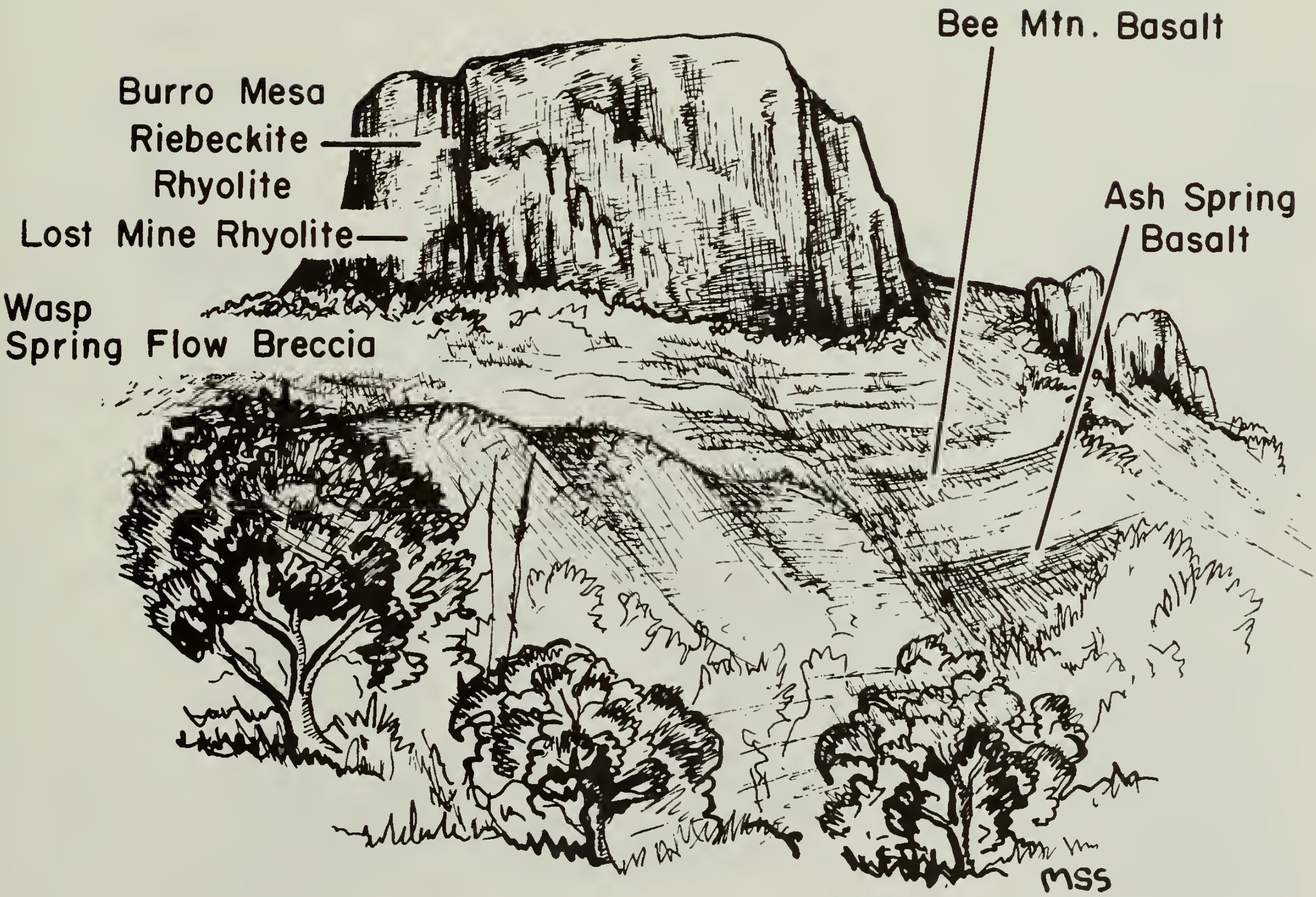

Burro Mesa
Riebeckite
Rhyolite
Lost Mine Rhyolite
Wasp
Spring Flow Breccia
Bee Mtn. Basalt
Ash Spring
Basalt
MSS

FIGURE 16

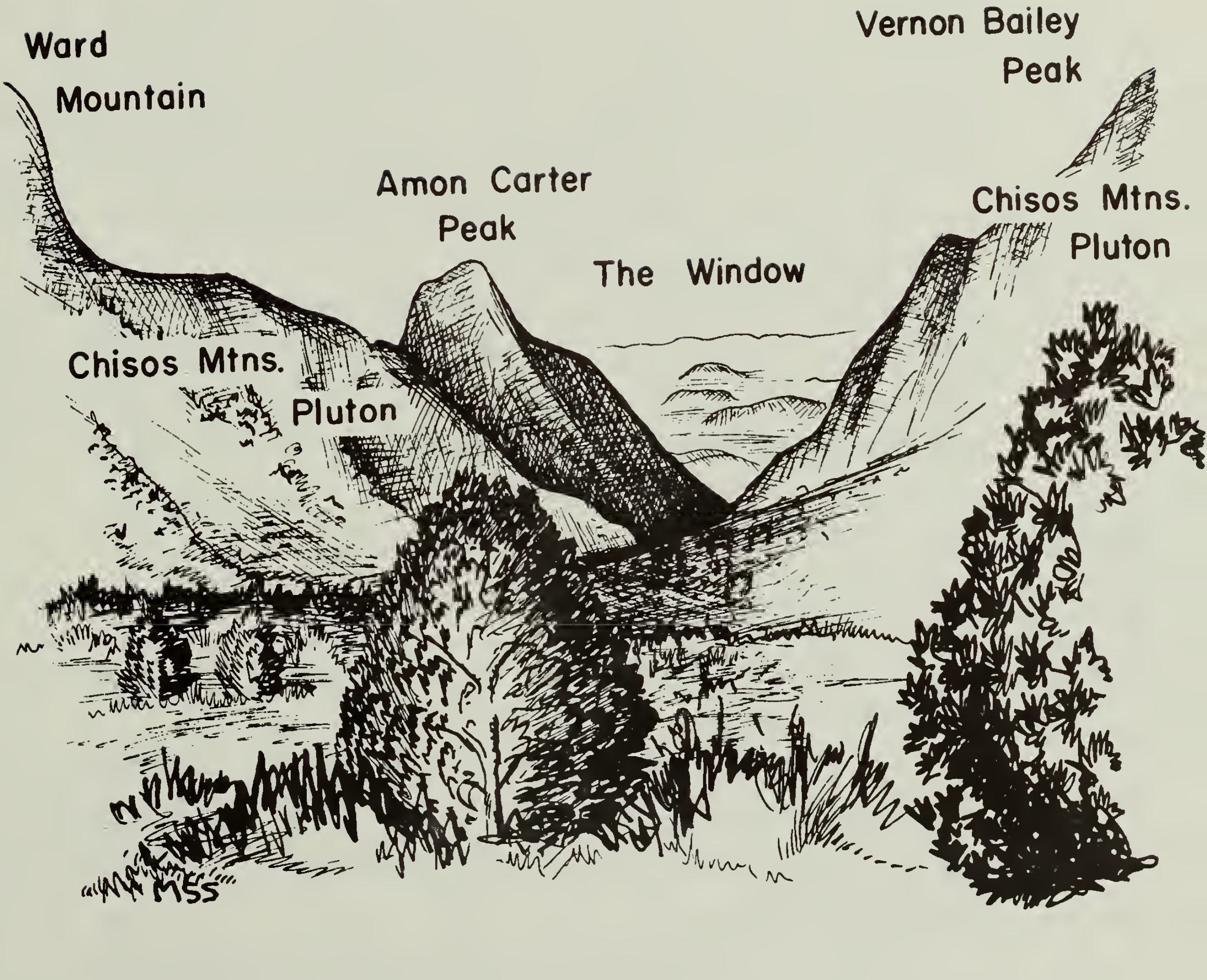

Ward
Mountain
Amon Carter
Peak
The Window
Vernon Bailey
Peak
Chisos Mtns.
Pluton
Chisos Mtns.
Pluton
MSS

FIGURE 17

the major part of the South Rim rocks were erupted (Ogley, 1979). By looking back one can still see Pulliam Bluff; Lone Mtn, a slightly discordant intrusion of alkalic microgranite in Aguja Fm., to northeast (left).

23.1 1.8 Panther Junction, Headquarters, Big Bend National Park; to the north is Lone Mtn; to the east northeast is Sierra del Caballo Muerto, a doubly plunging anticline in the Del Carmen trend exposing mainly Santa Elena Fm; from south to southwest are Pummel, Wright, and Panther pks, cut from the Brown, and Wasp Spring mbrs of the South Rim Fm; to the southwest is Pulliam Bluff and Pulliam Pk; and to the northwest are the Christmas Mts. As we turn northeast from Panther Junction, we leave the Park Block, though not the Park, at a point just west of the Dugout Wells Fault and Lineation, which continues north into the Christmas Mts Block.

27.2 4.1 Quaternary fanglomerate to the southeast rests, probably with slight angularity, on sandstone (braided stream deposits) of the ?Middle Eocene Big Yellow Mbr, Canoe Fm, and the colourful clays of the (?)Lower Eocene Hannold Hill Fm; on the east (right side of the road is the grave of Mrs. L.C. Hannold.

28.3 1.1 Base of Hannold Hill, in teh Hannold Hill fm.

30.3 2.0 Road going through exposures of Big Yellow Mbr, Canoe Fm.

31.3 1.0 Bridge across Tornillo Creek.

31.4 0.1 Road to fossil bone exhibit to the east (right); turn right into the Bone Exhibit parking area for Stop 11.

We are on sandstone and conglomeratic sandstone of the Wasatchian (roughly, Early Eocene) Exhibit Mbr of the Hannold Hill Fm, near the southeast end of a ridge supported by these relatively resistant rocks.

Suspended-load-dominated fluvial deposition persisted from the latest Cretaceous (Javelina Fm) to the Early Eocene, and the fine reddish sediments that surround this channel deposit are more representative of the style of deposition than this minor channel sandstone member. The Hannold Hill Fm represents the last gasp of the long-lived meandering stream depositional environment present in Trans-Pecos Texas during the earlier Tertiary, and its streams were apparently less sinuous than those that formed earlier deposits

(Rigsby, 1982).

Overlying Big Yellow Mbr, Canoe Fm, represents resumption of deposition after a break of some 6 - 9 ma, and a different, braided, fluvial, style of deposition (Rigsby, 1982). Although the sediments appear quite different, the direction of flow, the source suite of distant sedimentary and volcanic rocks, and the location of deposition had not changed. The Laramide Orogeny was over, and volcanism had not yet come to Trans-Pecos Texas. However, the Big Yellow Mbr is thin, usually not much more than 50 ft (15 m). The Upper mbr represents the building of one of the earliest constructive volcanic aprons in the region, and the start of the kind of mixed volcanic and sedimentary accumulation that we saw on the southwest side of the Park yesterday.

The original concept for the exhibit here, was to leave some bones in place at what was one of the more productive vertebrate fossil localities then known for the Park, and build a small shelter over them to prevent weathering and pilferage. Unfortunately, the exhibit became a prime targer for destructive vandalism. Most of the original fossils have long since been smashed by sledge-hammers, amgnum bullets, and other implements of destruction. Carefully made replicas of other bones from this site curated elsewhere have received the same treatment at least twice. But even though the bones are plastic, the locality serves as an opportunity to look at the pre-volcanic sediments of the area, and conveys some information about the kinds of animals that once lived here. Take a look at the exhibit, and remember that all of this rock was once thought to be Cretaceous until John A. Wilson found the vertebrate fossils that said it wasn't, and changed the story of the Laramide Orogeny.

32.0 0.6 Big Yellow Mbr., Canoe Fm (conglomeratic sandstone) resting disconformably on Hannold Hill Fm to west.

34.2 2.2 At 1:00 is Dagger Mtn; at 3:00 is Sierra del Caballo Muerto; at 5:00 is Roy's Pk; at 7:00 are the Chisos Mts; at 10:00 is the "Canoe," tilted Black Peaks Fm disconformably overlain by yellow congomeratic sandstone of the Big Yellow Mbr., Canoe Fm. This small syncline, produced by drag on normal faults bounding a graben, was locally known as "Canoe Valley," or "The Canoe" and gave its name to the

formation. Such structures and horst-created anticlines are fairly common in the Big Bend region, and have created some confusion in interpretation of tectonic style. At 12:00 is tiled Aguja Fm.

35.4 1.2 Exposures of Aguja Fm. near the road.

35.9 0.5 Road west to the Rosillos Ranch

36.2 0.3 Dagger Flat Rd., to east.

41.9 5.7 Dagger Mtn to east, is a fold in the Del Carmen trend exposing Santa Elena Fm; the Rosillos Mts to the west are formed from a volcanic and intrusive mass that helps to mark the position of the Presidio Zone, northern boundary of the Christmas Mts Block.

44.6 2.7 Bridge over Bone Springs Draw; about a mile to the east, this draw is joined by Nine Point Draw, and together (as Nine Point Draw), they cut through the more recently uplifted (mid-Tertiary or later) Laramide folds and thrust faults of the Del Carmen Mtns, to form the short but spectacular Dog Canyon (unfortunately, about a two mile, 3.2 km, walk from the pavement). At the east end of the canyon, on the north side of the draw, a thick unstudied Tertiary boulder conglomerate (probably a proximal fanglomerate) is in normal fault contact with Santa Elena Fm. The conglomerate is probably no older than earliest Miocene, and is more widespread to the south.

45.6 1.0 Road west to the Rosillos Ranch.

45.9 0.3 Bridge over Nine Point Draw.

46.3 0.4 Dog Canyon to east.

49.6 3.3 Persimmon Gap Ranch Rd., County Road (?).

49.7 0.1 Pull into the parking lot of the Range Station on the north (left) side of the road for Stop 12.

Persimmon Gap, the division between the Santiago Mts to the northwest and the Del Carmen Mts to the southeast, is a busy tectonic cross-roads. The trend of the mountain ranges marks what is often touted as the Laramide Front in this part of Texas, and is at least the site of earlier Eocene compression produced in the last episode of major activity in a left transpressional system that had persisted locally since at least the time of depostion of the Javelina Fm. The present elevation of the mountains is, however, the result of Tertiary, post-earliest-Miocene, high angle normal faulting (Basin and Range) along essentially the same trend. We are

near the position of the (here none too distinct at the surface) Presidio Zone, northern boundary of the Christmas Mts Block. Also, the young trend of the lineation that forms the western limit of the Estufa sub-block of the Park Block cuts across a southeastern corner of the Christmas Mts Block to reach the northeastern margin of the Sunken Block near here. The road through Persimmon Gap follows, roughly, the trend of an offsetting fault between the Santiago and Del Carmen mts., and the trend of teh Santiago Mts. is distinctly more westerly than that of the Del Carmen or Del Norte Mts. The structure of the Persimmon Gap area was ably described by Cobb and Pth (1980), but the complexity of the are is such that there is probably still something to be learned here.

To the southwest in the foreground is a hill of Aguja Fm below the plane of the thrust that has brought in the breaking wave of Glen Rose Fm that looms above in the mtn. The northeast face of the Aguja hill is a faultline scarp that approximates the position of a probably fairly minor Tertiary high angle normal fault that has brought the Anguja <u>up</u> into contact with what Maxwell (<u>in</u> Maxwell et al, 1967) has, probably correctly, identified as Pen Fm on the northeast side of the fault.

The slightly recumbent fold in Glen Rose Fm in the mountain to the south, has a core of much contorted and, at least in part, completely overturned (presumably by Ouachita thrusting), Maravillas, Caballos (here much reduced in thickness, and lacking good development of the middle, white novaculite mbs that we will see in the Marathon Basin), and Tesnus fms. On the northeast side of the mountain, the Glen Rose is repeated three times by thrust faults. The black hill to the east is composed of Maravillas and Caballos, overturned in the upper part of the hill, and resting at the base, facing us, on a wedge of Boquillas Fm, possibly Ernst Mbr.

Latest Mesozoic and Cenozoic events of regional and more local significance, evidence for which, and effects of which we have had a chance to see on this trip, are summarized in Figs. 18 and 19.

50.0 0.3 Particularly good view of the fold in Glen Rose Fm.

50.2 0.2 Persimmon Gap.

50.7 0.5 Paleozoic rocks of the Marathon Basin at road level, Lower

Tectonic Events, Southwestern United States and Mexico: Other Views

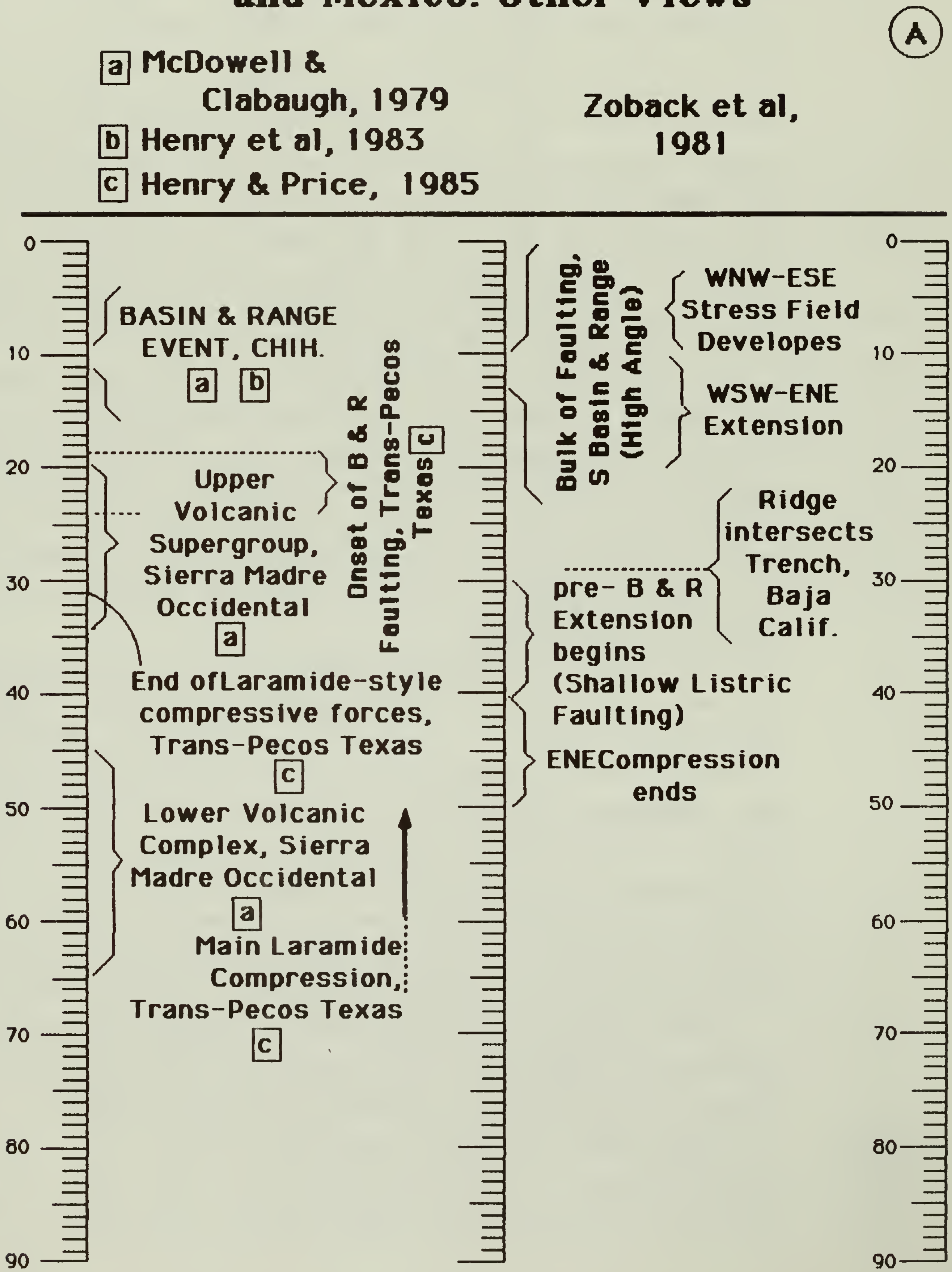


FIGURE 18a

Tectonic Events, Southwestern United States and Mexico: Other Views

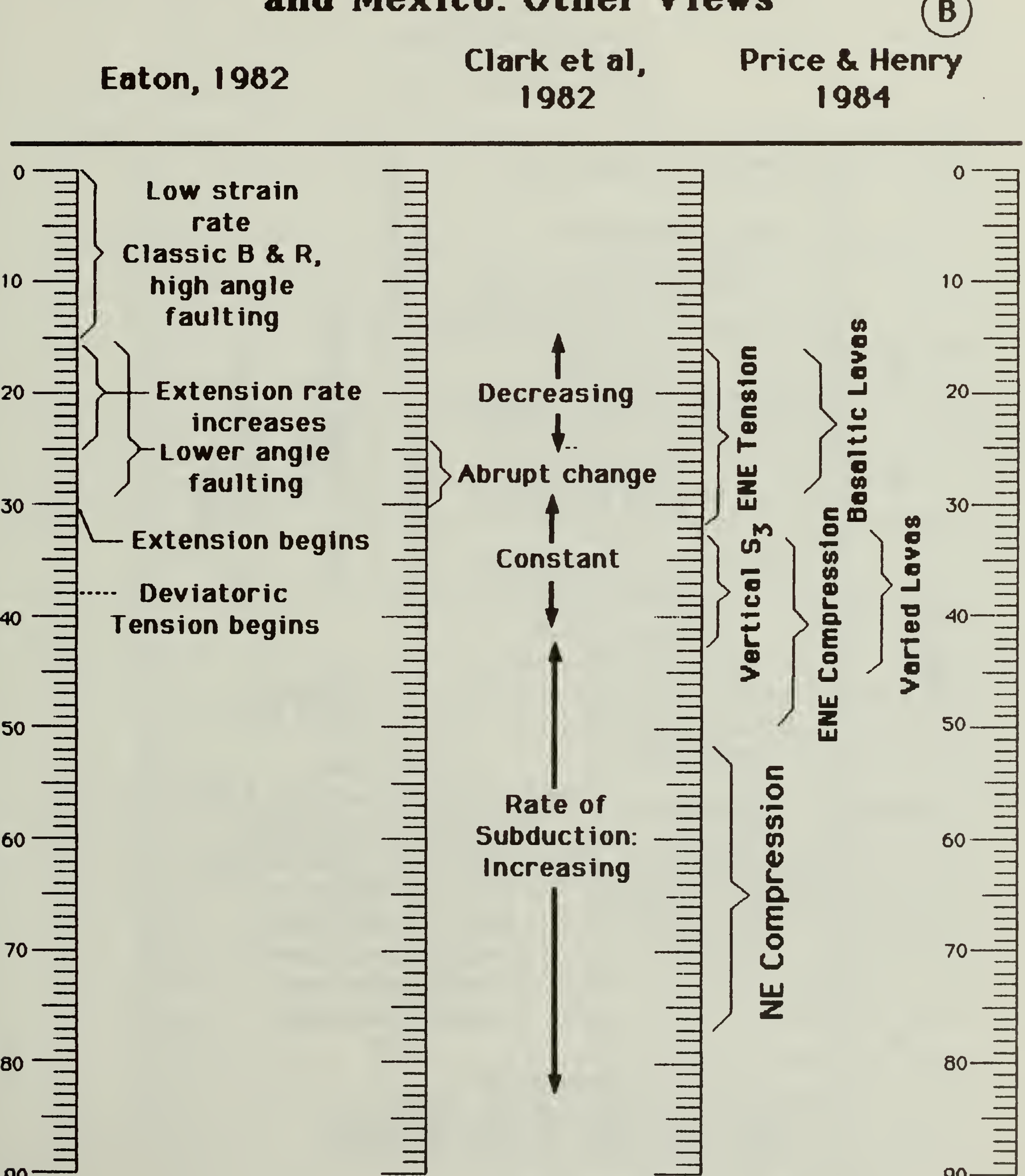
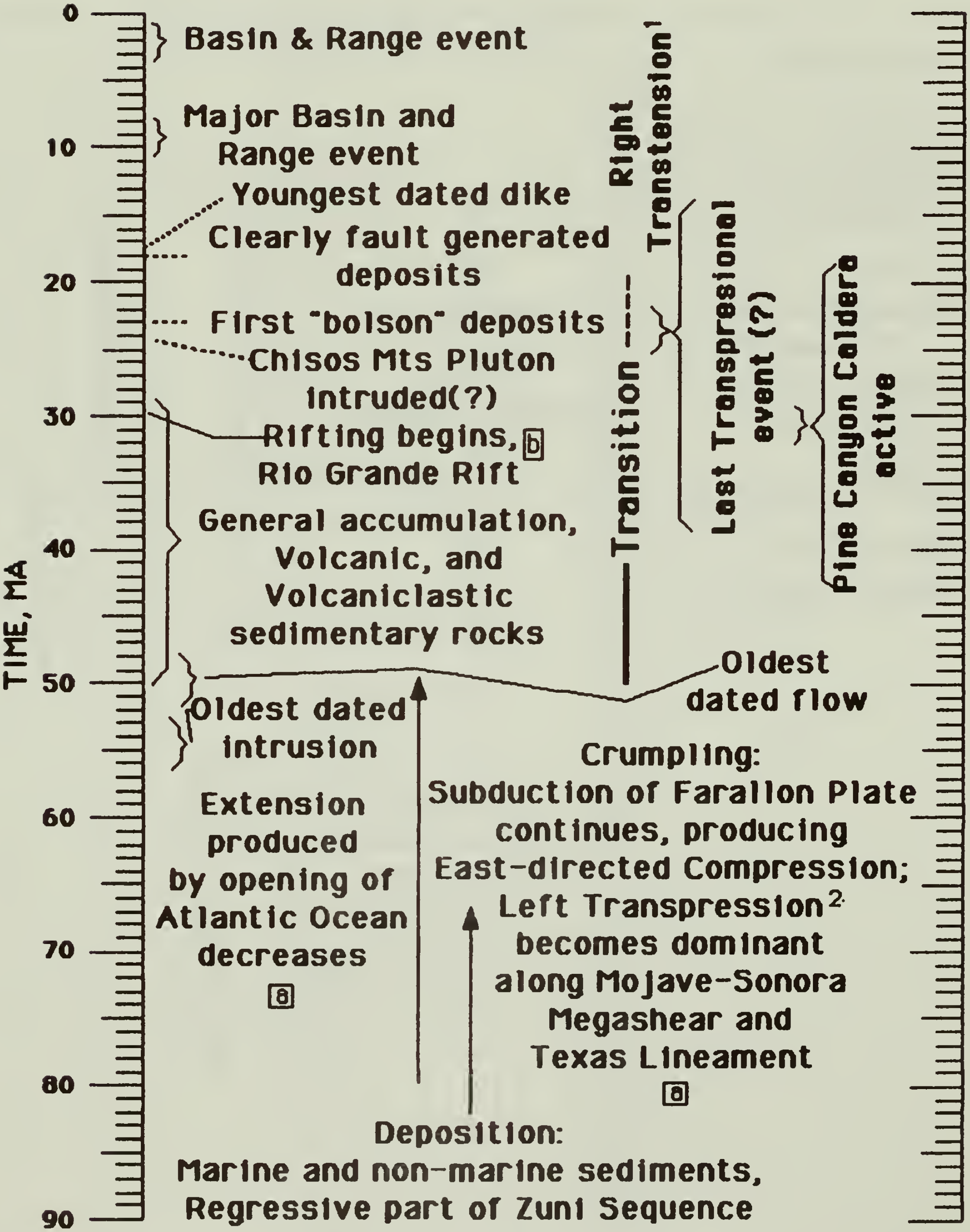


FIGURE 18b

Late Mesozoic and Cenozoic Deposition, Igneous Activity, and Tectonism: Big Bend Region

Modified from
Stevens & Stevens, 1985;
[a] Dickerson, 1985,
[b] Chapin and Seager, 1975



[1] Divergent right lateral wrench faulting
[2] Convergent left lateral wrench faulting

FIGURE 19

Cretaceous above a major angular unconformity.

51.3 0.6 Northern boundary, Big Bend National Park.

52.2 0.9 Road (FM 2627), southeast (right), to Black Gap Wildlife Refuge Area, and Stillwell Crossing, where the Fluorite from the Lalinda mines of Mexico (DuPont) comes into Texas.

54.1 1.9 Persimmond Gap Ranch gate.

56.0 1.9 Double Mills Historical Marker; two windmills on wooden towers were a long-time reminder of a former small settlement that once stood here.

56.3 0.3 Bridge where road crosses saddle in Santiago Mtns.

62.9 6.6 Bridge; Del Carmen Mtns., due south.

63.1 0.2 Tertiary intrusion (Black pk), due east.

54.8 1.7 Larger Tertiary intrusion through Glen Rose, to the east, Santiago Mtns. to the west, on the flank of the Marathon Uplift.

67.3 2.5 Good view of basal Cretaceous Glen Rose overlying Paleozoic rocks of the Marathon Basin with angular unconformity, to the east.

68.2 0.9 Bridge; a third Tertiary intrusion to the east.

69.2 1.0 Cretaceous, on right (east), over Paleozoic rocks of the Marathon Basin.

70.2 1.0 Roadcut through Caballos Novaculite.

71.1 0.9 Bridge.

73.2 2.1 South side, Threemile Hill, the crumpled leading edge of a thrust sheet in which Caballos Novaculite and the underlying Maravillas Fm. (dark cherts and limestones, for the most part). Santiago Mtns. at 12:00.

74.6 1.4 Another roadcut in Caballos Novaculite; the Caballos Novaculite is regarded as correlative with the Arkansas Novaculite, and therefore could be of Devonian through lowest Mississippian age (Stone and McFarland, 1981); very little is known from the Marathon Basin that could directly fix its age. In this area, King (1937) who named the formation, divided it into five members, of which the lowest, the middle (not everywhere clearly defined) and the highest are green cherts, and the second and third are true novaculites. The white rock that makes the sharp outcrops along ridge tops, is the truly novaculitic part of the Caballos Novaculite. Deposition of this unit has been much debated by R.L. Folk (silicified shallow water

carbonates), and E.F. McBride (starved basin), in many publications; I do not feel able to resolve the problem, though I believe that I have duplicated most of Folk's field observations. We are at the southwest end of the Tinaja Mountains, the crumpled upper plate of the upper plate of a thrust fault.

75.4 0.8 Bridge, north side of Threemile Hill; we have just crossed a thrust fault and are now in the lower sheet, in the Tesnus Fm.

78.4 3.0 Horse Mountain (for which the Caballos Fm. is named) at 4:00.

79.6 1.2 Road cut through Caballos Novaculite, the upper plate of one of the many Ouachita thrust faults seen at the surface by reason of the resistance to weathering (and nearly everything else) of the novaculite.

80.3 0.7 Santiago Mts to the west.

81.6 1.3 Roadside Park; Stop 13.

From Tauvers (1985, p. 73): "East and West Bourland Mountains are relatively open, doubly plunging (therefore noncylindrical) second order folds. .... East Bourland Mountain formed as a buckle fold detached from older rocks at the Woods Hollow level (the same level as the sole of the SST [Sunshine Springs thrust fault]). .... Duncan (1985) allows for the possibility of major telescoping within the Tesnus shale [sic] as well. These relationships demonstrate that strain in the .... area can be taken up by different mechanisms (i.e., faulting, folding) at different structural levels, separated by major decollement horizons ...."

Superficially, East Bourland Mtn is a simple situation; West Bourland and Simpson Spring mts are not. Since there is no vantage point along US 385 from which one can get a good look at West Bourland Mtn, I will leave my remarks about it at that. As nearly as I can tell, most of Tauvers' remarks quoted above apply to Simpson Spring Mtn as well as to the other two. The section exposed is simple: Maravillas Chert, and all, or nearly all of the mbrs of the Caballos Novaculite, the novaculite mbrs of which make the structure so readily visible. At the northeastern end with which I am somewhat familiar, the mtn consists (southeast to northwest) of a smaller anticline, a syncline and a larger anticline, probably slightly overturned (to the northwest) toward the northeast end of

the mtn. All of this is complicated by subsidiary folding, some of it evident in the Caballos; and minor tear and thrust faulting. To use the term from the quotation above, the Maravillas shows considerable telescoping.

A zone of severely brecciated Caballos separating over-and under-lying scrambled Maravillas suggested to King (1937) that Simpson Spring Mtn may be composed of two thrust plates. A very nearly straight lineation that cuts off the northeastern ends of Simpson Spring and East Bourland mts, terminates structures just to the east of the Sunshine Spring fold, and beyond. This lineation separates two major thrust sheets to the northeast and south west. The lineation, usually difficult to trace on the ground where it passes for considerable distances through pedimented Tesnus Shale, is marked in some places by a vertical breccia of novaculite, black chert (Maravillas, probably) and more puzzling limestone clasts.

82.2 0.6 Folds on Simpson Springs Mountain (see Fig 20).

84.0 1.8 East Bourland Mountain (see Fig 21).

85.3 1.3 Good view to the west of Simpson Springs, East Bourland, and Sunshine Springs mts (see Fig 20).

87.1 1.8 Good view south to Santiago Pk and west to the Del Norte Mts; trash barrel.

88.7 1.6 Road cut through Caballos Novaculite and Tesnus Fm.

89.4 0.7 The hills to the west (left), with open small folds in Caballos and Maravillas fms, are taken as the boundary between the Marathon Anticlinorium (east of them) and the Pena Colorado Synclinorium (to the west).

MARATRHON TO ALPINE ROAD LOG

(Modified from a portion of the Fourth Day Road Log, Muehlberger, Chandler, Dowse, and E.J. Dickerson, in P.W. Dickerson and Muehlberger, 1985, p. 27-30).

92.1 2.7 Intersection, US 385 with US 90; turn west (left) on US 90. Continue through Marathon, elevation 4043 feet. Marathon was established in 1889 as a townsite associated with the newly established Southern Pacific Railroad, and in years past was an important shipping site of Big Bend rubber obtained from a native plant (Guayule), fluorspar mined 125 miles south in the Boquillas

FIGURE 20

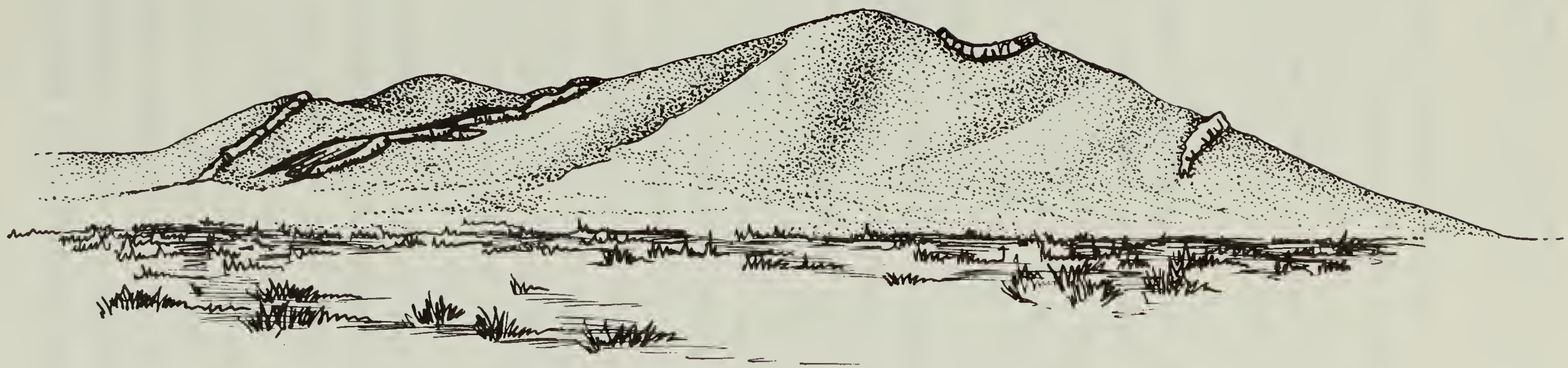


FIGURE 21

area of Mexico and later coming from the Lalinda mines southeast of Big Bend National Park, and mercury from mines in the Terlingua area.

92.5 0.4 Road to "The Post", a park maintained by the City of Marathon, where the Caballos Novaculite and the Maravillas Fm is well exposed, but unusually thoroughly fenced away from the public.

92.6 0.1 To the right, is the newly restored Gage Hotel. The hotel offers fine accommodations, quality meals and has a first-class catering service.

94.0 1.4 Highway 90 crosses the approximate trace of the Dugout Creek overthrust (king, 1937; Ross and Ross, 1985), here covered by alluvium; to the south Marathon Limestone overlies Gaptank Fm.

96.8 2.8 Roadcuts expose a facies of the Gaptank Fm different from the Gaptank exposed in the northern part of the Marathon Basin. Wolfcamp fusulinids occur in the carbonate rock. To the north, right, are the Glass Mountains forming the skyline. These represent a southeast-facing cuesta of Permian strata, and form the northwestern rim of the Marathon Basin. Their present dip is the result of Tertiary tectonism. The name for these mountains, from the Spanish Sierra del Vidrio, is perhaps derived either from the glassy appearance of the limestone itself, the presence of numerous silicified fossils in the limestone, or an erroneous transfer of a name for novaculite ridges south of Marathon.

99.3 2.5 Elephant Mtn, elevation 6200 feet, is the flat-topped mountain to the southwest (left) at 9:00. The scarp in front of Elephant Mtn is the face of the Del Norte Mtn. which form the rim of the Marathon Basin n this area.

101.3 2.0 Lenox Siding. Cathedral Mtn. and Skinner Ranch fms (Leonardian Series) overlie the Lenox Hills Fm (Wolfcamp Series) to the north (right), and the Dugout Mtns. to the south (left). The resistant ridge on the right is composed of Sullivan Pk Mbr, Skinner Ranch Fm. Apparently flat-topped Santiago Pk is visible to the south at 8:00.

104.7 3.4 Cathedral Mtn. is seen at 3:00 and is capped by the Lower Massive mbr of the Capitan Fm, or the uppermost mbr of the Vidrio Fm which here rests on sandstones and shales of the Word Fm.

109.9 5.2 The Word Fm is seen to the left at 9:00 dipping northward beneath

massive Capitan Fm. The Word Fm is the basin facies of the Vidrio Fm and was deposited here in the Hovey Channel.

111.9 2.0 Bissett Mtn. in the background at 3:00 is capped by Lower Cretaceous limestone, but the lower slopes are limestone conglomerates and redbeds of the Bissett Fm. The Bissett Fm, long considered to be Triassic, has recently yielded Lower Cretaceous dinosaur bones, and is probably correlative to the basal redbeds and conglomerates of the Glen Rose Fm (as seen at Persimmon Gap), and the Yearwood Fm, to the northwest, and west. The bones were found by Robert Wilcox, in the course of field work for his MS thesis. The bones have been examined by Wann Langston, an expert on dinosaur remains, at the Texas Memorial Museum, The University of Texas at Austin. Wilcox will shortly publish about the bones. The Bissett Fm lies unconformably on the Capitan and Tessey fms and contains pebbles derived from them.

112.6 0.8 Altuda Mtn to the south (left) at 9:00, is the north end of the Del Norte Mtns. and part of the west rim of the Marathon Basin. Beneath a cap of Lower Cretaceous limestone, cliffs of massive Capitan Fm lie on slope-forming beds of the Altuda Fm. The Bird Mine, abandoned just after the turn of the century, once produced silver-bearing galena from the Altuda and Capitan formations, along contacts with igneous intrusions at the north side of Altuda Mountain. The area still attacts mineral hunters. The quarry to the right is in Lower Cretaceous limestone.

114.2 1.5 Altuda Fm at 9:00. Note the denser vegetation here than on the Cretaceous hills to the west. The Altuda Fm, here siliceous shale, siltstone, and thin-bedded limestone, is the forereef, basinal facies of the Capitan Reef within the Hovey Channel, a southern arm of the Delaware Basin. The Hovery Channel is thought to have been the seeway between the Delaware basin to the north and the Marfa Basin to the southwest.

114.8 0.6 Ramsey Draw.

115.3 0.5 Roadside historical marker with an explanation of area geology. Volcanic terrain to the west (left), and Paleozoic sedimentary rocks to the east (right).

115.4 0.1 Junction of U.S. 90 with highway 67, the road to Fort Stockton to

the Northeast. Gently dipping Upper Cretaceious limestone forms the hills to the left.

117.0 1.6 In the low grey hills to the south (left), overlying Tertiary rocks are less vegetated than the Cretaceous (Eagle Ford - Austin gps) rocks. To the best of my knowledge, these rocks, both Tertiary and Cretaceous, have not been studied in many years; stratigraphic knowledge of them may still rest largely on studies done in the 1930's.

119.2 2.2 Roadcut through Tertiary volcanic rock.

121.0 1.8 Another roadcut through Tertiary volcanic rock, Crossen Trachyte, also seen in the mesa to the north.

121.7 0.7 Mitre Pk, an intrusion, is seen as a pointed peak to the north at 4:30, and the McDonald Observatory is located on distant Mount Livermore at 2:00. These are parts of the Southern Davis Mtns, a Tertiary volcanic pile.

123.7 2.0 Southern Pacific Railroad Station, Alpine, Texas.

END OF DAY 3 ROAD LOG

END OF FIELD TRIP ROAD LOGS

An Outline of the Cenozoic Geologic History of the Area Around Big Bend National Park

by

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Introduction

Purpose: This paper is intended to provide a brief, and opinionated overview of the Cenozoic geologic development of the Big Bend National Park area, with special emphasis on the last 50 ma. Discussion of the geologic history in the Big Bend region has increased in the last decade; much emphasis has been placed on the application of tectonic theory to evidence provided by igneous petrology, geochemistry, and structural geology. Particularly important are contributions by Dickerson (1980, 1985), Goetz and Dickerson (1985), Henry (1979), Henry and Bockoven (1979), Henry et al (1983), Henry and price (1985), McDowell (1979, 1961), Muehlberger (1979, 1980), Muehlberger and Moustafa (1984), and Price and Henry (1984, 1985). Of special importance are papers by Anderson and Schmidt (1983) and Longoria (1985) that establish a broad tectonic framework, within which events in the Big Bend can be discussed.

Previous work: The importance of work of John A. Wilson and Ross Maxwell (Maxwell et al, 1967) can not be too much emphasized. Maxwell's work, in addition to general geological mapping, is particularly important because it established the stratigraphic framework for a substantial part of the Cretaceous System in the Big Bend region, as inspection of Stratigraphic Charts 3 and 4 will show. Cretaceous rocks form a large part of the topography, and

express important parts of the structure in the Big Bend region. John A. Wilson found and studied vertebrate fossils demonstrating that many rocks previously thought to be Cretaceous were Paleocene and Eocene (Wilson, 1952; and in Maxwell et al, 1967) and in the process changed the story of Laramide deformation in Trans-Pecos Texas. Wilson also found the vertebrate fossils that proved the existence of Miocene deposits in the Big Bend region, and put the discussion of Basin and Range structure into a much less hypothetical context. The fossils, and the deposits in which they occur were studied by the Stevens' (Stevens, J.B., 1969; Stevens, M.S., et al, 1969; Stevens, M.S., 1977).

Yates and Thompson were allowed to publish, in 1960, their description, discussion, and thorough mapping of the Terlingua Mining district, done in the early 1940's. One may dispute some of their interpretations, as we do in the light of later information. One must be cautious about disputing their basic geologic observations; there is no better set of maps of the district.

Responsibilities of the authors, and location of the study: Our original interest in the Big Bend region was lithostratigraphy (J. B. Stevens) and vertebrate biostratigraphy (M.S. Stevens). We have come to recognize that stratigraphy approaches many tectonic problems with a degree of independence, and provides needed information. The areas considered are shown in Figs. 1, 4 and 5 (Note: to avoid duplication, figures are referrenced in the order in which they appear in the guidebook). Conclusions presented involve radiometric analyses, and observation of the structures produced by the tectonic environment, in addition to stratigraphic studies. Our participation in radiometric analyses extends only so far as collection of samples; we are very much indebted to F.W. McDowell, C.D. Henry, J.L. Jordan, and others for help and advice on this topic.

Fossils from localities in Big Bend National Park were collected under a series of United States Department of the Interior Antiquities Act permits, 1952-1985, issued to the Texas Memorial Museum. All fossils are curated at that museum.

Tectonic Setting of Big Bend National Park

Earlier views: Udden (1907) recognized that the Chisos Mountains sit in a structural low defined on the northeast by the trend of the Del Carmen and

Santiago mountains, and on the southwest by the face of the erosionally separated blocks called Mesa de Anguila (U.S.), Sierra Ponce, and Sierra Diablo (both in Mexico). Udden called the structural low the "Sunken Block," and the name persists as more apt than King's (1935) "broad synclinal area." King (1935) brought together and organized a wealth of detail from his own experiences and the work of Baker (1927, 1928; and personal communications), Adkins (1933; manuscript works; and personal communications), R.E. King (personal communications; but see also 1939, portions of which were in hand by 1935), and other workers. He produced an overall view of the structure of the Sunken Block that was remarkably little changed until the 1970's.

Current model: Anderson and Schmidt (1983) proposed a model for the tectonic development of Mexico and the immediately adjacent United States. Longoria (1985) gave details of the geology of Coahuila and Chihuahua, and devised a related right transpressional model for Jurassic activity which is useful as a background for later events, particularly those of the Laramide Orogeny (DeCamp, 1961, 1985; Moustafa, 1983), and at least the earlier of the Basin and Range events (Stevens and Stevens, 1985), as observed in the Big Bend region (Fig. 4A, theory, and Fig 4B, our view of reality). It also seems to fit reasonably well with (almost surely is a function of) the setting of earlier events as proposed by, for example, Muehlberger (1980), and Goetz and Dickerson (1985). However, the model is not complete without inclusion of details at smaller scales. Dickerson (1980) sought to emphasize the importance of east-west trends in Trans-Pecos Texas that had previously attracted little attention. Though these trends are doubtless very old, and, as Dickerson (1985) notes, not oriented entirely ideally for the Cenozoic systems, it is our conviction that they have played a very important roll by forming blocks within blocks. The significance of the tectonic pattern illustrated for the Big Bend region by Stevens, J.B., and M.S. Stevens (1983), shown in Fig. 4B, is two-fold: there are blocks within blocks within blocks; Fig. 5 is our diagramatic version of this. And the form of the blocks is reflected by a variety of structures, not necessarily of significantly different ages because of their different forms.

Time and scale within the model: The nature of the stresses, transpressional or transtensional, and of the lateral movement, right or left, has varied through time in the overall system with variations in relative movement between plates. At a smaller scale, variations in behavior of sub-plate units becomes

important, as exemplified in the Trans-Pecos region by Goetz' (1985) discussion of the Salt Draw Graben. Scale, precise location within the system, and the ability of data to descriminate these matters are very important considerations for one examining local effects, as a considerable literature demonstrates. Compression and tension are very commonly local terms when used in the Big Bend region. Aydin and Nur (1982), Aydin and Page (1984) have shown the regional coexistence of compression and tension in wrench faulting tectonics, and Aydin and Reches (1982) and Muehlberger and Merritt (1985) have given specific examples of this kind of situation in the Big Bend region (respecitvely, the Terlingua Mining District, and a small area in Big Bend National Park, near Boquillos Canyon). Consideration of lateral motion is, of course also a matter of scale and location.

It should be emphasized that many of the trends to be discussed below are old, with demonstrable Jurassic (Longoria, 1985), late Paleozoic (Pearson, 1978; Muehlberger, 1980; Goetz and Dickerson, 1985), and even Precambrian (Muehlberger, 1980; Dickerson, 1980) episodes of activity. Oldani (1986, this guidebook) provides an overview of the many events that have helped to establish the basic structural elements of the region, and a context for their investigation.

The Sunken Block and the Park Block: Of the blocks that Longoria (1985) illustrated (reproduced as our Fig. 4A), the one that extends southeast from the part of the Texas Lineament between, roughly, Van Horn and a position northwest of the Paisano Caldera area, into Mexico, is the one of particular interest for this study. In Trans-Pecos Texas, its northeastern boundary is defined thus: the northwest-striking Santiago Mountains and a parallel part of the Chalk Draw Fault align well with the general trend of the Walnut Draw Fault Zone, which, in turn, aligns along a course that would graze the Paisano Pass Caldera, and faults beyond it to the northwest, approaching the Texas Lineament. The Santiago Mountains extend southeast from Del Norte Gap to end officially at Persimon Gap, a structurally important area strategically located at the approximate intersection of northwest, north-northwest, near northerly, and east-west trends. However, despite a slight kink at Persimon gap, the trend of the Santiago Mountains appears to continue southeast to Dog Canyon. Beyond that point, the more north-northwesterly strike of the Del Carmen Mountains delineates the northeast margin of the block, but the trend continues to coincide approximately with Longoria's (1985) La Babia Fault, southeast into

Coahuila, Mexico. The western side is marked, from northwest to southeast, by the Rim Rock and West Chinati fault zones, an un-named fault zone across the northeast side of the Bofecillos Mountains to near Lajitas, and the Terlingua Fault Zone, and approximately coincides with Longoria's San Marcos Fault. These northwest-striking boundaries would be second order trends in a shearing zone between the Texas Lineament and the "Walper" megashear in Mexico, an idea that is very close to a suggestion made by Moody and Hill (1956).

The block thus defined can, if one sets aside a great deal of complication, be said to have a lengthwise (southeast-northwest) sag, a portion, centered approximately on Big Bend National Park that lies, in part, below the structural level of major blocks to the northeast and southwest Figs. 5A, 5B, and 5C, are an attempt to organize, at increasing scales, a geometrically simplified developmental view of the general structural outlines of the portion of the larger block that has sagged. The (nearly) east-west trends are the zones proposed by Dickerson (1980); specifically, from north to south, the Shafter Zone (roughly, between the Chinati Caldera and the area marked by the east-west part of the Chalk Draw Fault, and east-west part of the Tascotal Mesa Fault, east to the Persimmon Gap-Dog Canyon area), the Terlingua Zone (from the approximate position of Lajitas, where there is a pronounced kink in the southwest boundary of the major block, east, to include east-west parts of the Terlingua Monocline, and the Christmas Mountains "Anticline"), and something that ought to exist in the neighborhood of, or south of, the Santa Elena Zone. We tend to favor an east-west trend from the southeastern end of the Sierra Diablo, where the Terlingua Fault dies out in Mexico. Most or all of these are old zones of weakness, with a long history of movement.

There is geophysical evidence marking the Shafter Zone (Dickerson, 1980) as a major crustal discontinuity; Pearson (1978, 1981) suggests Paleozoic (Ordovician-Permian) down-to-the-north displacement possibly in excess of 10,000 ft (3048m) on the Shafter Zone in eastern Presidio County. In the Cenozoic, the block between the Shafter and Presidio zones tilted to the south and west; apparent motion on the Presidio, and Terlingua zones can be generalized as down-to-the-south, more strongly so on the latter. The blocks may have rotated slightly, so that east end is higher but all have sub-blocks behaving independently, to produce more obvious effects. In further discussion, Udden's (1907) Sunken Block becomes the part of the major block between the San Marcos and La Babia faults (Fig. 4A) from the Shafter Zone

southeast to a poorly known southern boundary in Chihuahua and Coahila. The block between the Shafter Zone and the Ruidosa Zone, to the north, appears to be high, and further to the northwest major parts, at least, of blocks have subsided to form the Marfa, Valentine and Lobo bolsons.

Big Bend National Park sits in the structurally lowest major subdivision (mosaic block) of the Sunken Block, referred to below as the Park Block. Similarly, the block north of it will be called the Christmas Mountains block (see Fig. 5B, 5C). The Park Block is a complex rhomb, about 50 mi (81 km) in its east-west dimension, and perhaps 33 mi (53 km) from north to south. Young faulting with major trends commonly, but not invariably, parallel to the northwest-southeast oriented boundaries, has complicated the northern, and presumably the unstudied southern boundaries.

Subdivisions of the Park Block: The Park Block is divided into three parts: The Delaho, Chisos, and Estufa sub-blocks. The Chisos Sub-block is essentially a horst between two complex grabens. Southwest of the Chisos Sub-block, the Delaho Sub-block, structurally the lowest part of the Park Block, is bounded on its northeast side by the Burro Mesa Fault Zone, more northerly in orientation, and less clearly defined than the Terlingua Fault Zone, which is, locally, the southwestern boundary of the Sunken Block, the Park Block, and the Delaho Sub-block. On the northeast side of the Chisos Sub-block, the Dugout Wells lineament (and, in part, the fault of the same name), and normal faulting parallel to and coincident with the Del Carmen Mountains, define the wedge shaped Estufa Sub-block.

Developmental history of the Park Block: The old northwest oriented structural trend was reactivated by the stages (Chapin, 1985) of the Laramide Orogeny, particularly the second stage (DeCamp, 1981, 1985; Longoria, 1985; Dickerson, 1985). That set of events has strongly influenced all that came later, by fracturing and warping the thick, and, in its lower parts, comparatively competent Cretaceous System in the area. The reactivated fractures have acted as zones of weakness in the later Tertiary, and Quaternary (Dietrich, 1966; Muehlberger et al, 1978; Muehlberger, 1979; Muehlberger and Merritt, 1985). Price and Henry.(1984, 1985) contend that the Quaternary and current tensional (right transtensional, more properly) stress field in the area has essentially a N 10 degree W orientation sufficiently different from those which established and reactivated the old fractures. The newly discovered Dugout Wells fault lies within a much longer Dugout Wells lineation which runs diagonally across

the Sunken Block in a north-by-northwesterly direction. The lineation is clearly visible on Plate 1 in the area south and southeast of the Chisos Mountains, where it appears to disturb Quaternary alluvium, perhaps very young Quaternary alluvium. Apparently it ends near Persimmon Gap.

Latest Mesozoic - Cenozoic Stress Regimes and Igneous Events

Left transpression and transition: Cenozoic tectonic history of Trans-Pecos Texas is usually divided between an earlier compressional regime marked by Laramide folding and thrust faulting, and a later tensional regime marked by high angle normal faulting. If the words transpression and transtension are substituted, and their connotations accepted, then for a rough outline, this remains satisfactory, though as noted below, there is a degree of exception to be taken to both the Laramide and Basin and Range designations.

Various authors' timing of events discussed here are outlined in Fig. 16. Our suggestions, modified from Stevens and Stevens (1985) together with those of Dickerson (1985) are given in Fig.19. Distributions of K-Ar age determinations for stylistic categories of igneous events in Trans-Pecos Texas and Chihuahua, Mexico, are shown by Fig. 22. Age determinations in the range 34-22 ma graphed by McDowell and Clabaugh (1979) if included in Fig. 22, would increase the contribution from Chihuahua, particularly the western part of that state, but probably would not change the overall shape of distributions for that time. As Fig. 18 and 22 show, recognition and timing of events in other areas corresponds remarkably well with that in far West Texas and adjacent Chihuahua, even when the basis of definition is quite different (eg, Fig. 22F; and Damon and others, 1981; Clark and others, 1982). However, note that plots in Fig.22 can not discriminated clearly between transpression, and transtension. The use of the names "Laramide" and "Basin and Range" for these stress regimes (or their effects) seems to depend heavily on the similarity of the timing.

The effects of the latest Cretaceous through about mid-Eocene left transpressional regime, suggest for the Big Bend region, a variance, first discussed in some detail by King (1935), with conditions to the north and west where the Laramide Orogeny is recognized. Muehlberger (1980) has shown that the principal evidences of compression, folding, and thrust faulting, outline a combination of the Diablo Platform and the part of the major block defined

above, from the Park Block northwest. The sense of thrusting generally seems to be into this combination. Within the platform the compressional regime reasserted and established a northwesterly structural grain whose elements have strongly affected and limited the expression of subsequent tectonism; but response to the compression was mild (Muehlberger, 1980; DeCamp, 1981, 1985). South and west, in the Chihuahua Trough, response to this regime was greatly magnified (DeFord, 1969, Gries, 1980). Muehlberger placed the end of transpression at about 50 ma, and the beginnings of extension at about 27 ma. Price and Henry (1984) have shown clear evidence from style of magmatic emplacement for Oligocene compression (Fig. 22B), but it is less clear that regional transpression is necessary. Henry and Price (in press, 1985) note that after 32-30 ma there is no evidence from style of intrusion for compression, and some for extension (Fig. 22B, 22C). They extend Laramide compression to, and begin Basin and Range extension at, that time.

Stevens and Stevens (1985) expressed a degree of concern at this major extension of the concept of the Laramide; the use of the term "Laramide" for post-Eocene structures and events does not seem reasonable, and use of the term for any events in the Big Bend region may run the risk of making of it a time term. It would seem appropriate to recognize a transitional period, as is done in the main Basin and Range province (Zoback and others, 1981, Eaton, 1982). From about 50 to at least 26-24 Ma (Fig. 18) there is evidence of co-existing tension and compression (Fig. 22B, 22C, and 22D; and discussion below), but the compressional events were milder than those earlier, and extension did not produce anything approaching the structural relief that was to come later. Stevens and Stevens (1985) discussed structures in the Terlingua Monocline where it becomes involved with the Terlingua Zone, from Tres Cuevas Mountain to the Cigar Mountain Graben. The Terlingua Uplift is not a Laramide structure, and both the uplift and modifications of the Terlingua Monocline at its southern margin are quite possibly as young as latest Oligocene. Yet the modifications of the monocline (Stevens and Stevens, 1985) would appear to us to be produced by left lateral motion in a position, and at a scale that may be compatible with a right lateral system between the Texas Lineament, and the "Walper" megashear, but not with transtension. In contrast the Terlingua Monocline itself could be compatible with right transtension. We either hide it this problem under "transition," or acknowledge that we do not understand it. The transition period would also include the episode of silicic (including

comenditic) volcanism (Fig. 22E) and intrusion, and much of the intrusion and extrusion of mugearite and hawaiite (Carman et al, 1975; Barker 1977; Parker and McDowell, 1979; Parker, 1983).

Right transtension: Right transtension becomes the third and current (Dietrich, 1966; Muehlberger and others, 1976; Muehlberger, 1979, 1980; Henry, 1979) regime, though, as previously noted, it may be desireable to subdivide that. In the context of a shift from transpression to transtension, it may not be possible to apply Eaton's (1982) dictum that initiation of extension is a more "fundamental tectonic phenomenon" than the beginnings of Basin and Range structure (high angle normal faulting in the Big Bend region). Some high angle normal faulting is suspected from about 26-27 ma (Delaho Sub-block, Stevens, 1969; Terlingua Zone, McKnight, 1970), and this style of deformation became increasingly prominent, as shown by the increase in dike intrusion (Fig. 22C). Most of the structural relief seen in the Big Bend area today, is the result of events younger than 20 ma. All of this later Tertiary and Quaternary faulting appears to be high angle normal faulting. Stratigraphic evidence for this, discussed below, agrees with the geophysical modeling done for the Presidio Bolson (Mraz and Keller, 1980), and with the conclusions of Mauger (1981) and Henry and others (1983). Listric faulting is the early tensional style in the main Basin and Range province (Zoback and others, 1981; Eaton, 1982; Anderson and others, 1983) and in the Rio Grande Rift (Cape et al, 1983).

Listric faulting should be one of the first effects seen according to an important tectonic model for Basin and Range extension (Wernicke, 1981; Allmendinger and others, 1983). Thus far, listric faulting, except for minor slump features, has not been demonstrated for the Big Bend region; we suspect that the "Basin and Range" structures in and near the Sunken Block are fundamentally different from those in the Great Basin. But, once again, the timing is very much the same.

Cenozoic Depositional Patterns in the Big Bend National Park Area

Later Mesozoic-earlier Cenozoic sedimentation patterns: Discontinuous deposition in shallow basins in the Big Bend National park area, extending from the later Cretaceous to approximately 54 ma (top of Hannold Hill Formation; early Eocene, Wasatchian, or Ypresian [Schiebout, 1974; Wilson, 1980; Berggren

et al, 1985]). The pattern of sedimentation from later Cretaceous into the earlier Tertiary is reasonably straight forward: the Pen, Aguja, and Javelina fms. can be taken as recording a regression: upward, deposition shifts from shallow shelf shales deposited below wave-base and in increasingly muddy waters, to littoral and deltaic deposits (probably small, river-dominated deltas) of the Aguja, and delta plain to flood plain deposits in the Javelina Formation. Broadly, the rocks record progradation of a shoreline while crustal downwarping continued, but probably at a decreasing rate. If a 50 gigaton boulder bashed the planet 66.5 ma ago, the event is not strikingly recorded in the Big Bend area. Deposition was by no means continuous, but omissions appear to have resulted from increasingly frequent by-passing and hiatus, rather than any clearly evident erosional vacuity. Deposition of the Black Peaks and Hannold Hill formations continued the suspended-load-dominated meandering river style established in the latest Cretaceous, though with a slight trend toward occasional deposition of coarser material, as the Exhibit Member, Hannold Hill Formation, shows. Deposition was probably slow, and in the sense of Wilson's (1959) concept of Transfer, this may be primarily the result of a lack of space.

It is our understanding (personal communication to J.B.S. from J.A. Schiebout, 1985) that despite some searching, no record of any Cretaceous-Tertiary boundary event has been found in the Big Bend region. Microfossils found are transported relicts of many older units, and the environment of deposition was too strongly oxidizing to preserve pollen. Indeed, the colorful banding that marks the Javelina and earlier Tertiary deposits is probably the result of diagenetic enhancement of paleosols. Some of the effects are, however, the result of recent weathering; some purple units prove, upon energetic excavation, to be dark grey. Because the area of exposure lies almost entirely within a national park, many samples processed have been taken only from the surface. Were it not for the vertebrate fossils found and studied by J.A. Wilson (early and middle Tertiary mammals; see particularly Wilson, in Maxwell et al, 1967; and Wilson, 1952, 1977, 1980), and Wann Langston (dinosaurs, pteranodons, and alligators) and their students at The University of Texas at Austin (particularly Schiebout, 1970, 1973, 1974), the stratigraphic complexity of these handsome mudrocks would probably be unrecognized. As it is, the problems of distribution, and thickness, and as a result, those of environmental and tectonic interpretation of the units are far

from solution.

Paleocene and lower Eocene rocks are found, almost entirely, along and near the less distinct part of the Terlingua Zone that separates the northeastern part of the Park Block from the southeastern part of the Christmas Mountains Block. The Cretaceous Javelina Formation occurs more widely (most parts of the Park Block, Christmas Mountains Block, and the block north of that; west in Mexico; and northwest in the Tierra Vieja), but its distribution also seems more restricted than that of underlying formations. What is not clear is whether the restricted distribution of the Tornillo Group is the result of restricted deposition due to initial late Cretaceous-early Tertiary crustal down warping in the left transpressional system in this particular part of the Sunken Block, or to subsequent erosion.

<u>Earlier mid-Cenozoic depositional patterns</u>: In Big Bend National Park, the mid-Cenozoic is represented by the disparate formations of the Big Bend Group. To the north and northwest of the Park, the mid-Cenozoic is represented, more completely, by the Buck Hill Group. But whereas the Big Bend Park Group rests, in part, on older Tertiary rocks (as noted above), the Buck Hill Group rests, usually with slight angularity, on a faulted and eroded Gulfian Cretaceous terrain of low local relief. The part of the Buck Hill Group that is in any way comparable to the Big Bend Group (Member 9 of the Rawls Formation is emphatically not comparable, though the Rawls is part of the Buck Hill Group) ranges in age from 50-47 ma to about 27 ma, and is substantially better dated, both by fossils and radiometric dates, than the Big Bend Group.

The basal unit of the Big Bend Group, the Canoe Formation, has two quite different members. The Big Yellow (basal) Member, which rests with marked disconformity on sediments of the Tornillo Group (Maxwell et al, 1967; Rigsby, 1982, 1986), is roughly correlative with the Lower member, Devil's Graveyard Formation (Stevens et al, 1984). Styles of deposition differ markedly between the later Eocene units and the upper part of the underlying Tornillo Group in some respects: the Big Yellow Member and the Lower member, Devil's Graveyard Formation, are sandstones and conglomerates deposited by (probably closely related) major subtropical braided streams that flowed year around. However, as with the older units, flow was to the east and southeast, and the clays that occur with the braided stream deposits are nearly indistinguishable from those of the younger part of the Tornillo Gp. Furthermore, the sandstones, with substantial amounts of fairly locally derived sedimentary (limestone) clasts,

and volcanic clasts derived from more distant sources (Stevens, 1979; Risgby, 1982), are not compositionally very different from those near the top of the Tornillo Group. Stevens (1969) found, about three miles east of Cerro Castellan, an exposure of varicolored clays in association with a very well rounded limestone conglomerate. At the time, this was regarded as Javelina Formation, but it now appears that there are other possibilities.

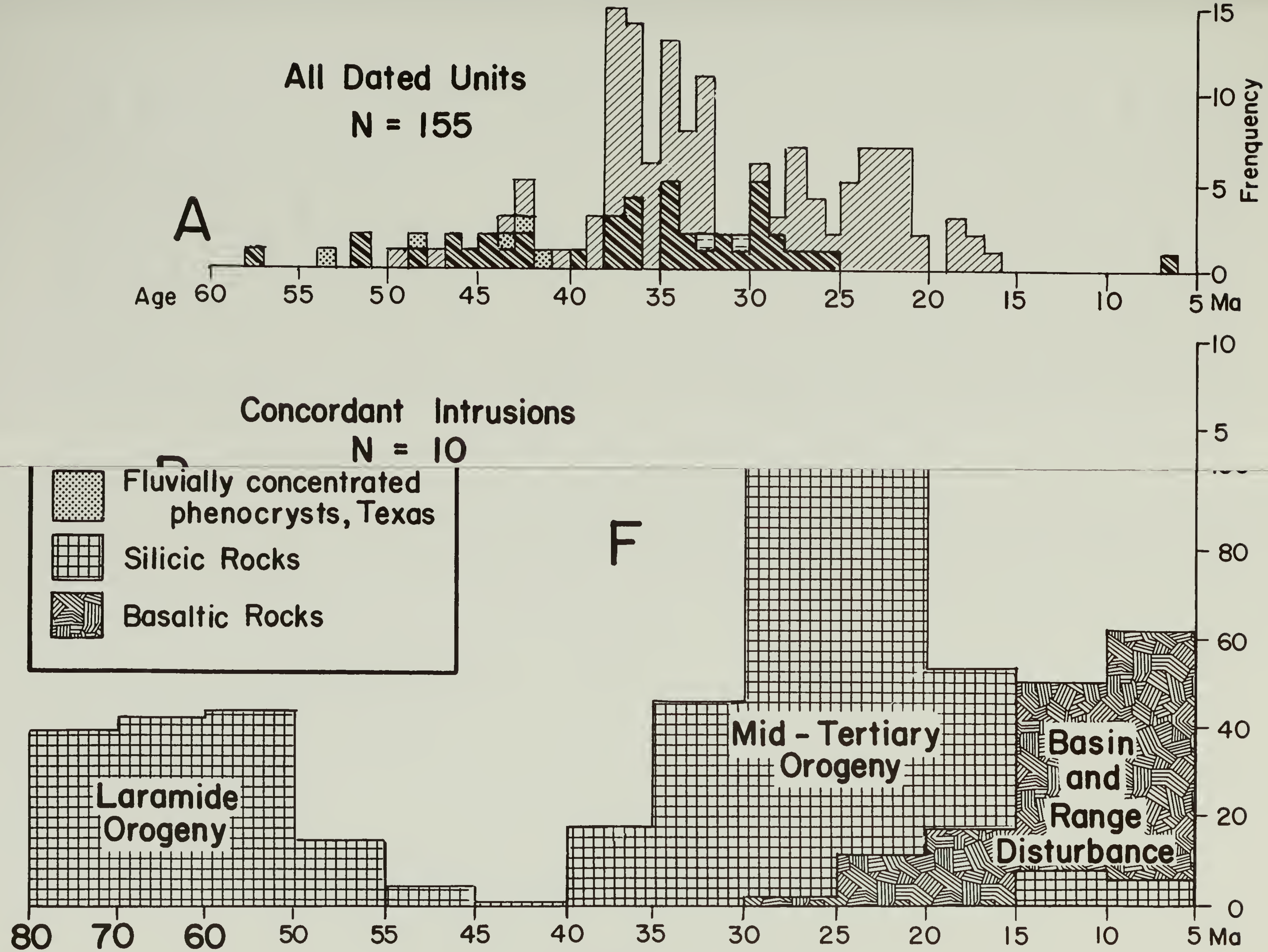
The Devil's Graveyard Formation thins northward against Cretaceous rocks of low but noticeable relief; a very broad valley or basin was progressively filled. There is convincing evidence that there was syndepositional faulting (the faults are minor, with displacements on the order of 20 - 50 ft, or 6 - 15 m, and do not seem to define any trend). But faulting had little effect of sedimentation, beyond minor ponding. Sediments were supplied from the west (on the basis of age of volcanic activity, western Chihuahua seems the best possibility), and, in large part, doubtless, passed on to the southeast, to find an eventual home in the Rio Grande Embayment. Sediments of the Devil's Graveyard Formation younger than about 45 ma took on increasingly the appearance of a constructive volcanic fan, but without any great change in direction of transport. Instead of easterly to southeasterly, the direction became northeasterly to easterly; there can not have been much change in the ultimate destination. Rigsby (1982) found a marked change in the directions of transport in the volcanic apron portion (Upper member) of the Canoe Formation. She found that the volcanic apron spread into the northeastern part of the Park Block and the adjacent part of the Christmas Mountains Block from the south and southwest, and suggested a deflection of through-going drainage northward. This seems reasonable; we are less inclined to agree, on the one hand, that volcanism in the present position of the Chisos Mountains was the source of material for the apron. On the other hand, the source for the sediments of the Upper member of the Canoe Formation was more purely volcanic and more mafic than that for the volcaniclastic part of the Devil's Graveyard Formation.

Three points can be made on the basis of the preceding synopses of earlier and early mid-Tertiary deposition. The unconformity at the base of the Canoe and Devil's Graveyard formations spans about 4-6 ma, from about 54 to 50-48 ma (later Wasatchian and early Bridgerian or later Early to earlier Middle Eocene) and probably represents the principal Laramide event. Resumption of deposition was along a trend consistent with what evidence we have for the site of earlier deposition; there may have been a persistent structural low. Furthermore, by

about 50 ma, there does not appear to have been any significant barrier to inflow from the west, or outflow to the east and southeast.

Mid-Cenozoic deposition: The episode of volcanism, and the building of constructive and destructive volcanic aprons (Walton, 1978, 1979) away from the immediate vicinity of the volcanic centers lasted from about 45 ma to 27 ma. In and near the Park, the Upper member of the Canoe Formation, and the Chisos and South Rim formations were deposited during this time. To the north and west, the rocks of all but the very oldest part of the Buck Hill Group are part of this style of deposition. It should be noted that Member 9, Rawls Formation, is not included in this statement. Member 9 is 3-4 ma younger than the rest of the Rawls Formation (see Stratigraphic Chart 7), and a part of the next stage in sediment accumulation. Volcanic activity within given eruptive centers in the Big Bend area is summarized in Fig. 22 and Stratigrphic Charts 5, 6 and 7. Direction of sediment transportation would be expected to be away from volcanic centers in the Davis, Chinati, Bofecillos, and the Chisos Mountains, and/or from Sierra Rica, for the more sedimentary portions of the Goat Mountain member of the Chisos Formation, and the Devil's Graveyard Formation (Stevens et al, 1984). In large part this seems to be true, although the Davis Mountains do not seem to have supplied much sediment to the south. But the Goat Mountain member remains puzzling, in that transportation was not so much away from, as toward the Chisos Mountains. Transport direction, in other words, tends to have been consistent with that for other contemporaneous deposits to the north and northwest, despite a different source.

One other point should be made. The beginnings of volcanic apron deposition are recorded on the southwestern part of the Christmas Mountains Block, and the Estufa Sub-block, but not on the Delaho Sub-block (Maxwell et al, 1967; Stevens, 1969). But the Chisos Formation, as Maxwell et al (1967) noted, is almost entirely confined to the Chisos and Delaho sub-blocks, and again, the southwest corner of the Christmas Mountains Block. We are reasonably certain that the Chisos Formation once covered Mesa de Anguila, and the Sierra Ponce, extending across the boundaries of a Sunken Block that did not then exist as such. The flows from Pine Canyon Caldera (South Rim Formation) went to the west and southwest, and are not known from the Estufa Sub-block, or areas away from the Chisos Mountains beyond that sub-block. Our only suggestion is that about 42 ma ago, contemporaneously with the extrusion of the Alamo Creek Member of the Chisos Formation (see Stratigraphic Chart 5),



All Dated Units
N = 155
A
Frenquency
Age 60 55 50 45 40 35 30 25 20 15 10 5 Ma
15 10 5 0
Concordant Intrusions
N = 10
Fluvially concentrated phenocrysts, Texas
Silicic Rocks
Basaltic Rocks
F
Laramide Orogeny
Mid - Tertiary Orogeny
Basin and Range Disturbance
80 70 60 50 55 45 40 35 30 25 20 15 10 5 Ma
10 5 80 60 40 20 0

FIGURE 22

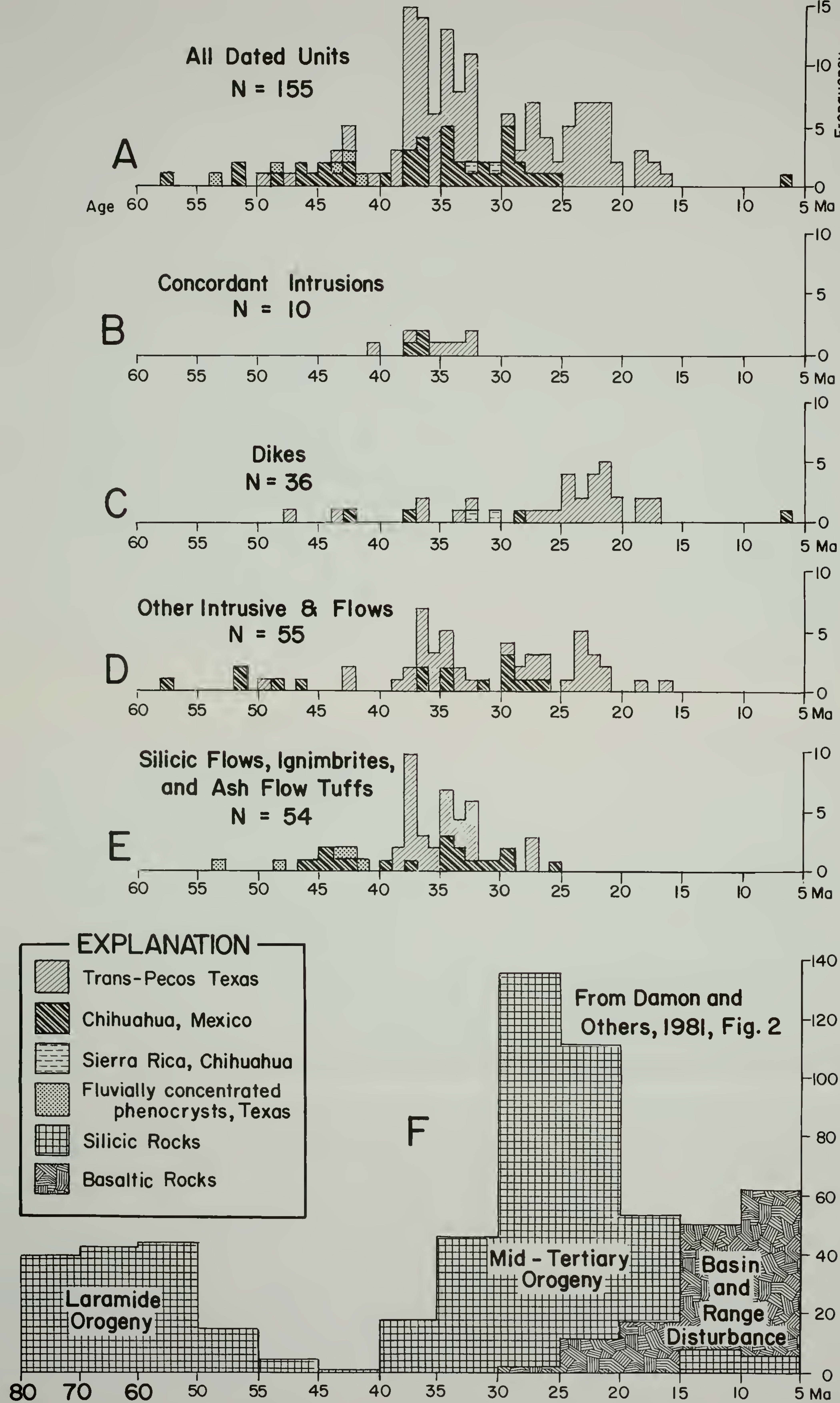

All Dated Units
N = 155
A
Frenquency
Age
Concordant Intrusions
N = 10
B
Dikes
N = 36
C
Other Intrusive & Flows
N = 55
D
Silicic Flows, Ignimbrites, and Ash Flow Tuffs
N = 54
E
EXPLANATION
Trans-Pecos Texas
Chihuahua, Mexico
Sierra Rica, Chihuahua
Fluvially concentrated phenocrysts, Texas
Silicic Rocks
Basaltic Rocks
F
From Damon and Others, 1981, Fig. 2
Laramide Orogeny
Mid - Tertiary Orogeny
Basin and Range Disturbance
5 Ma

FIGURE 22

an area, possibly bounded on the north by the Terlingua Zone, began to subside, creating a basin that trapped both sediments and volcanic rocks. A question that ought to be answered more definitely than we can at present, is: where was the source for the sediments that the basin trapped?

Despite this evidence of mild warping, there are two thin, widespread ignimbrite deposits, the Mule Ear Spring and Mitchell Mesa rhyolites, 34 and 32 ma, respectively. These and the lateral persistence of some of the volcanic members of the Chisos Formation (Alamo Creek, Bee Mountain, and Tule Mountain members), indicate that regional topographic relief was low to remarkably flat during much of the middle Cenozoic episode of volcanic and volcaniclastic accumulation. The doming of the Solitario, contemporaneous with the eruption of the Mitchell Mesa Rhyolite, is clearly evident both in the deformation and beveling of older deposits (Wilson et al, 1979), and in the deposition of coarse conglomerate shed from the dome (Stevens et al, 1984). Similarly, there is clear stratigraphic evidence for doming that preceded development of the Pine Canyon Caldera (Maxwell et al, 1967; Ogley, 1979) at approximately 30 ma in Big Bend National Park. But except for local effects in the near neighborhood of such activities, there is little evidence of strong and general disturbance until about the time of the lull in igneous activity (26-25 ma, Fig. 22A; see also Fig. 19) and the beginning of noteworthy normal faulting.

<u>Miocene and younger deposition</u>: From the end of the preceding episode of general accumulation of sedimentary and volcanic rocks, until about 23 ma, the Big Bend region was purely a source area for southern Texas Gulf Coast deposition. For example, Morton (1985), identified a part of the Frio Formation as weathered volcanic debris, and dated its arrival at the coast as probably somewhat before 23 ma. It was in the interval before the last stages of sediment accumulation in the Big Bend region that the Chisos Mountains Pluton was intruded Ogley, (1979; Dailey, 1979), and subsidence of the Delaho Sub-block began. At about 23 ma deposition began and filled a series of episodically formed, relatively small basins (see Stratigraphic Chart 8, and Figure 19). Deposition of the earliest Miocene Lower member, Delaho Formation, on the Delaho Sub-block, and of at least two other units of similar age, one of them a part of Member 9, Rawls Formation, as Stevens, J.B., and Stevens M.S. (1983) and Stevens and Stevens (1985) noted, is problematic; the deposits may record either minor subsidence of blocks or climatic change.

Major subsidence of the small basins (bolsons) probably began after 20 ma.

From about that time to the present, most of the modern structural relief along the boundaries of, and within the Sunken Block developed, and there are correspondingly thick deposits of later Tertiary, and Quaternary bolson fill to show this. These sediments, clearly associated with the right transtension regime, include the Smoky Creek Member, Delaho Formation, on the Delaho Sub-block, and deposits of late Tertiary-Quaternary sediment to the east of the Chisos Mountains, on the Estufa Sub-block. The Delaho Sub-block continued to subside sporadically; it was not until fairly late, about 9 ma ago that the Estufa Sub-block began to subside, to make the Chisos Sub-block truly a horst; substantial subsidence of this sub-block probably dates as young as lower Quaternary (Stevens and Stevens, 1985, and work in progress). The subsidence amounted to from 1000 (Estufa Sub-block) to 3000 (Delaho Sub-block) ft (305-915 m), without much discordance of attitudes of bodies of infilling sediment.

By about lower Quaternary time, both of the graben systems had filled, and the Chisos Mountains must have been largely buried in their own debris, and that from surrounding areas. The Chisos Mountains, Sierra del Carmen, Mesa de Anguila, Terlingua Uplift (at least the southern part), and most of the other topographic features that add to the scenery of the Big Bend National Park area were unburied in the last part of the Quaternary. Conservatively, later Pleistocene exhumation during the development of the modern Rio Grande drainage added 1800 ft (550 m) to the stature of the Chisos Mountains.

Summary

<u>Tectonic styles</u>: There may have been five Laramide pulses (Muehlberger, 1980, citing evidence from Maxwell et al, 1967) or the two that Chapin (1985) sees in the Southern Rockies to the northwest. The left lateral transpression dominant in the Big Bend area from later Cretaceous through at least much of the Eocene probably produced its major effects in and near the very large block in which the Park Block sits, during the later Early and Middle Eocene. Within the block, the effects were mild, immediately to the northeast, and impinging on the southern margin of the Park Block, folding and thrust faulting are much more prominent. Such effects are, again, more prominent to the southwest and west, but somewhat more distant.

Subsequent to the prolonged period of left transpression, there was

something approaching a lack of style for over 20 ma. During this time there was major igneous activity including the suite of mugearitic-hawaiitic intrusives and flows, comenditic intrusive bodies and flows, and some large scale ignimbrites. But structural effects are only locally major, and beyond a tendency, sometimes honored in the breach (Pine Canyon Caldera and the Chisos Mountains Pluton), for volcanic centers to be close to, or on, old trends, there is little evidence to support much structural activity along those trends.

About 27-20 ma ago, intrusion of dikes and movement on a few high angle normal faults marked a renewal of tectonic activity along the old major trends, and the beginnings of a new style, right lateral, rather than left. Right transtension was well established, and has been episodically (Stevens and Stevens, 1985) active from about 20 ma to present. The faulting style, commonly referred to as Basin and Range, does not appear to be developmentally the same. We are not certin that any great realignment of stresses is needed to emphasize more northerly trends in this system, but it does appear that these trends are active currently.

<u>Depositional styles</u>: Deposition of the Javelina, Black Peaks, and Hannold Hill formations is much more complex than we have time or knowledge to discuss; nevertheless, there is no striking break in that suite of sediments, in terms of depositional style. However, the increasing restriction of the area of deposition, breaks in deposition, and the mingling of sand grains derived from erosion of sedimentary sources with material from more distant volcanic sources, probably do mark episodes of mild Laramide deformation. Our only difference with Maxwell et al (1967) on this point would be to emphasize that warping was not severe enough to produce pronounced topographic effects, or interfere with the style of deposition. There is a substantial change in style of deposition between the Hannold Hill Formation and the Canoe Formation, and this probably marks more energetic lower to mid-Eocene Laramide activity.

Change from slow accumulation in a large scale humid subtropical braided river-plain to more rapid accumulation on constructive volcanic aprons is sharp between the two members of the Canoe Formation in the Park, and gradual in the more complete record of the Devil's Graveyard Formation. It is an important change regionally, and eventually must have changed major river drainage considerably. Transport to the east and southeast remained dominant in smaller aggrading braided streams supplied with an enormous quantity of fresh

volcaniclastic sediment. Despite minor warping, relief in the region must have been low away from volcanic and intrusive doming centers.

With the end of the tremendous oversupply of volcanic and volcaniclastic sediment, and the absence of a through-flowing drainage to import materials, general accumulation soon ceased, and erosion became dominant, doubtless enhanced by tectonically increased relief. Miocene and later deposition occurred in bolsons whose floors, without much tilting, subsided episodically, and eventually, deeply. The Rio Grande is a later Pleistocene river to which we are much indebted for exhuming a lot of once deeply buried evidence, without destroying all of it.

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EPISODIC SEDIMENTATION IN THE RIO GRANDE-TRANS PECOS REGION AS RELATED TO PERIODS OF TECTONIC ACTIVITY

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ABSTRACT

The Rio Grande-Trans Pecos region of West Texas and northeastern Mexico is a highly complex geologic province, where a repetition of tectonic events since the Precambrian has resulted in the continual formation, destruction, and reformation of structural receiving basins. For each phase of tectonic activity that has occurred, syntectonic sediments were deposited. The position and character of these deposits in the record section serves to date and characterize each tectonic event.

The local tectonic history of the region is a product of the influences of the overall tectonics of the North American craton. The location of the area in the south central portion of the active North American craton points to this fact. Major tectonic events with associated syntectonic sedimentation took place in the region during the Precambrian, late Paleozoic, early to middle Mesozoic, late Mesozic to early Cenozoic, and late Cenozoic.

The earliest syntectonic sedimentation in the region occurred during the Precambrian, in response to alternating rifting and compressional events. During the late Paleozoic (Mississippian to Permian), the Ouachita compressional event resulted in a series of syntectonic deposits, accounting for essentially all of the Paleozoic synorogenic sedimentation. From early to middle Mesozoic, syntectonic conglomerates accumulated around the perimeter of the Chihuahua Trough. The Rio Grande Embayment became a primary area for syntectonic sedimentation with the late Mesozoic uplift, folding, and thrusting activity of the Laramide Orogeny. A late Cretaceous clastic sequence accumulated in the northwestern end of the Rio Grande Embayment (Maverick and Sabinas Basins). Synorogenic sedimentation in the Rio Grande Embayment continued into the Cenozoic, culminating with lower Eocene deltaic sediments. Syntectonic sedimentation associated with the Laramide event also continued to

take place within the Rio Grande-Trans Pecos region. In middle Cenozoic time, Basin and Range deformation resulted in syntectonic sedimentation in intermontane basins. Also at this time, tectonically derived sediments once again accumulated in the Rio Grande Embayment.

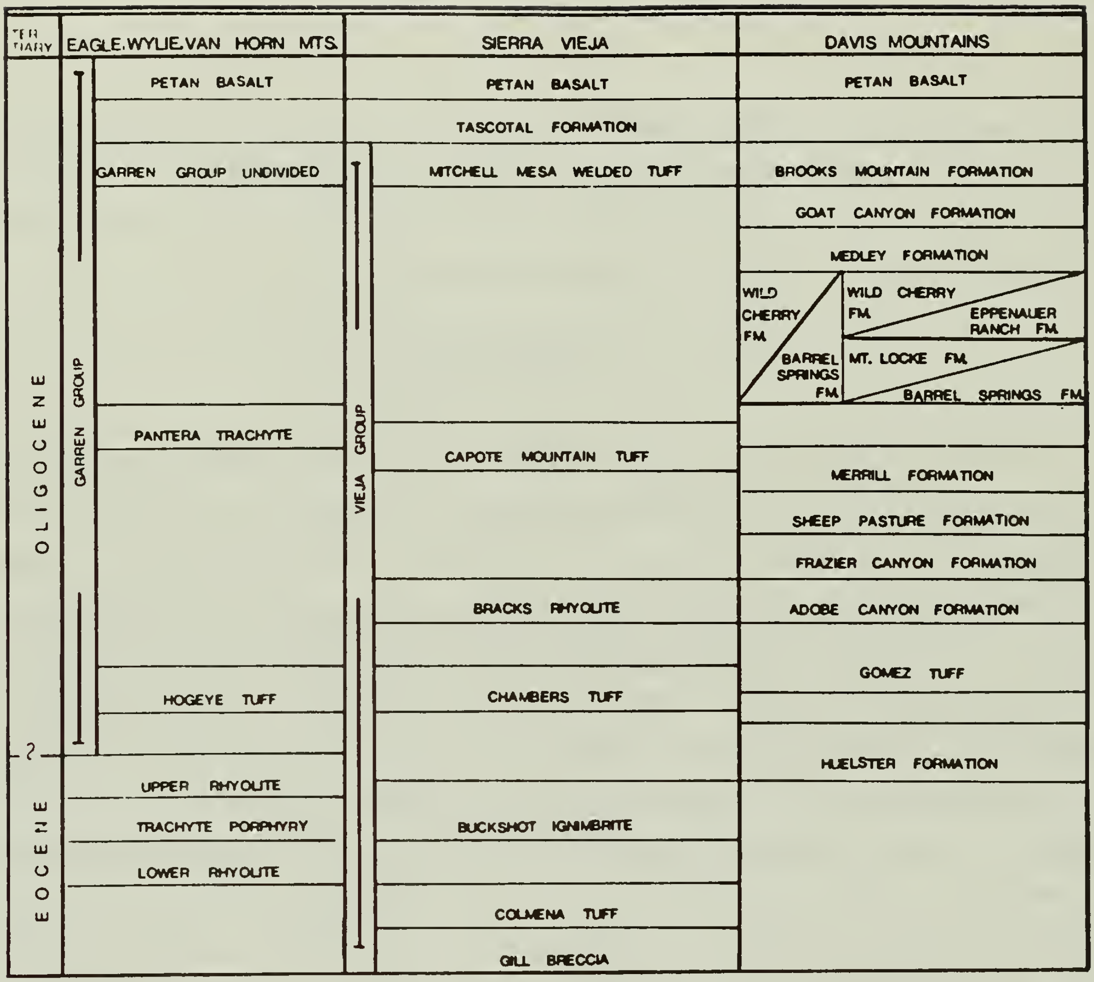
INTRODUCTION

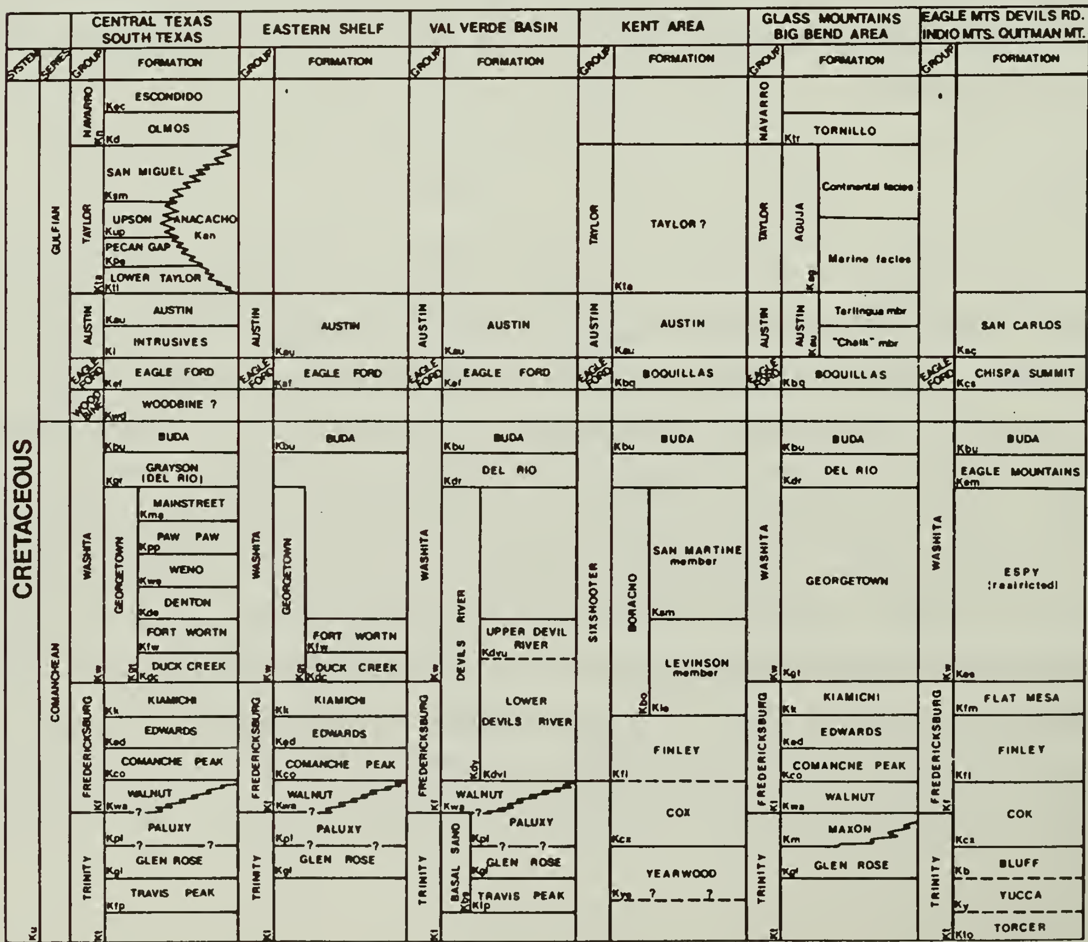
The Rio Grande-Trans Pecos region is a highly complex geologic province, both structurally and stratigraphically. The region has received a variety of sediments in a diverse variety of structural receiving basins, commencing in the Precambrian and continuing throughout the course of geologic history. Figure 1 is a stratigraphic column which illustrates the large sequence of formations that have been identified in the region. These sediments have been deposited in varying basinal settings that have largely been created or altered by the repetition of tectonic events that have affected the region. Major tectonic events with associated deformation have been documented during the Precambrian, late Paleozoic, early to middle Mesozoic, latest Mesozoic to early Cenozoic, and late Cenozoic. Each of these events had a profound effect on the type of sedimentation taking place in the region. It would seem that typical syntectonic deposits would remain as evidence for each pulse of deformation that has occurred.

PURPOSE

The episodes of tectonic activity that have affected the Rio Grande-Trans Pecos region have resulted in multiple syntectonic deposits. These deposits are clear evidence of the magnitude of the deformation associated with each of the tectonic events that have occurred. The texture and composition of each deposit are indicators of the various rock lithologies that were exposed, eroded and subsequently redeposited at different locations during and after each orogenic event. These rock components are also an indicator of transport direction, which indicates where the primary deformation was taking place. The stratigraphic position of these deposits illustrates the timing of the various orogenic pulses that have occurred. Therefore, the objective of this paper is to discuss these various syntectonic deposits and their tectonic origin, in order to better understand the complex geologic history of the Trans Pecos-Rio

STRATIGRAPHIC NOMENCLATURE





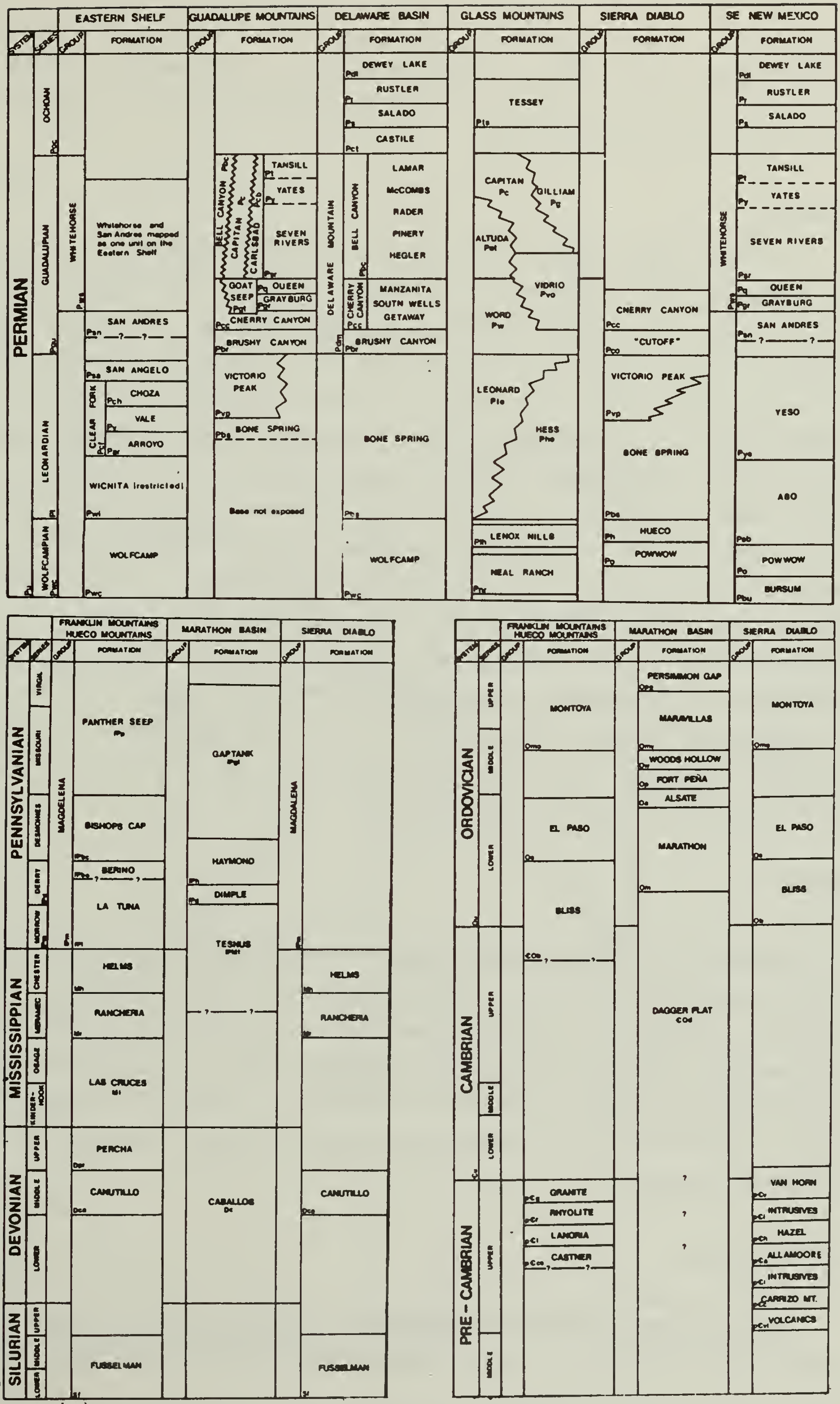


Figure 1. Regional stratigraphic column of the Rio Grande-Trans Pecos region. (from Dickerson et al, 1980, 1985)

Grande region. The paper is being prepared as supplementary information for the Houston Geological Society field trip guidebook to the Big Bend National Park area in the spring of 1986.

LOCATION

The Rio Grande-Trans Pecos region is located geographically in West Texas and Northern Mexico, south of the Pecos River to the vicinity of the Rio Conchos River in Mexico (Figure 2). The location of the major geologic features of the region is illustrated in Figure 3. The complex structural setting is the result of the area's location being situated where repeated orogenic activity has taken place and is merged into a structural mosaic. For the most part, three major tectonic events account for the structural elements of the region. Figure 1 illustrates the position of the various sediments of the region in the stratigraphic column. These rocks range in age from Precambrian to recent. A localized stratigraphic column showing the nomenclature of the rocks exposed in the Big Bend area (which is the area of interest for this field trip) is illustrated by Stevens (1986, this Guidebook). Geomorphically the region is located in an arid erosional environment, where the topography is the product of Basin and Range structures superimposed on Laramide features. Figure 4 illustrates the principle physiographic and tectonic features exhibited in the region.

METHODS

The paper is designed as a compilation of data available from previous works related to syntectonic sedimentation in the area of study. The primary procedure utilized has therefore been literature research. The data derived from various published papers is presented here in a format specific to sedimentation related to orogenic activity in the Rio Grande-Trans Pecos region. An effort to cite the various authors and their research has been made throughout the paper.

PREVIOUS WORKS

Over the years numerous researchers have conducted their work in the Rio Grande-Trans Pecos region. These workers have studied many different aspects

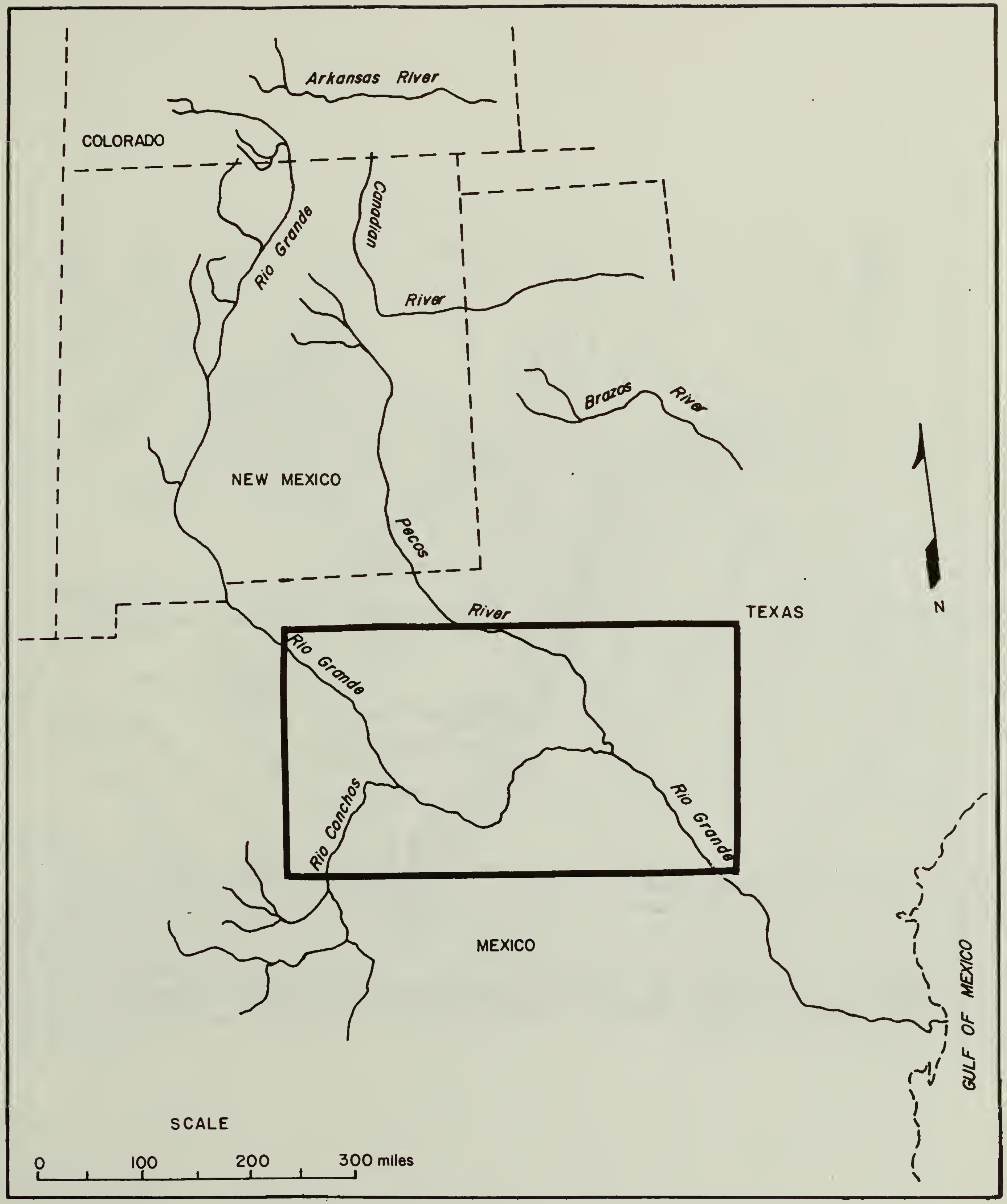


Figure 2. Geographic location of the Rio Grande-Trans Pecos region. (adapted from Belcher, 1975)

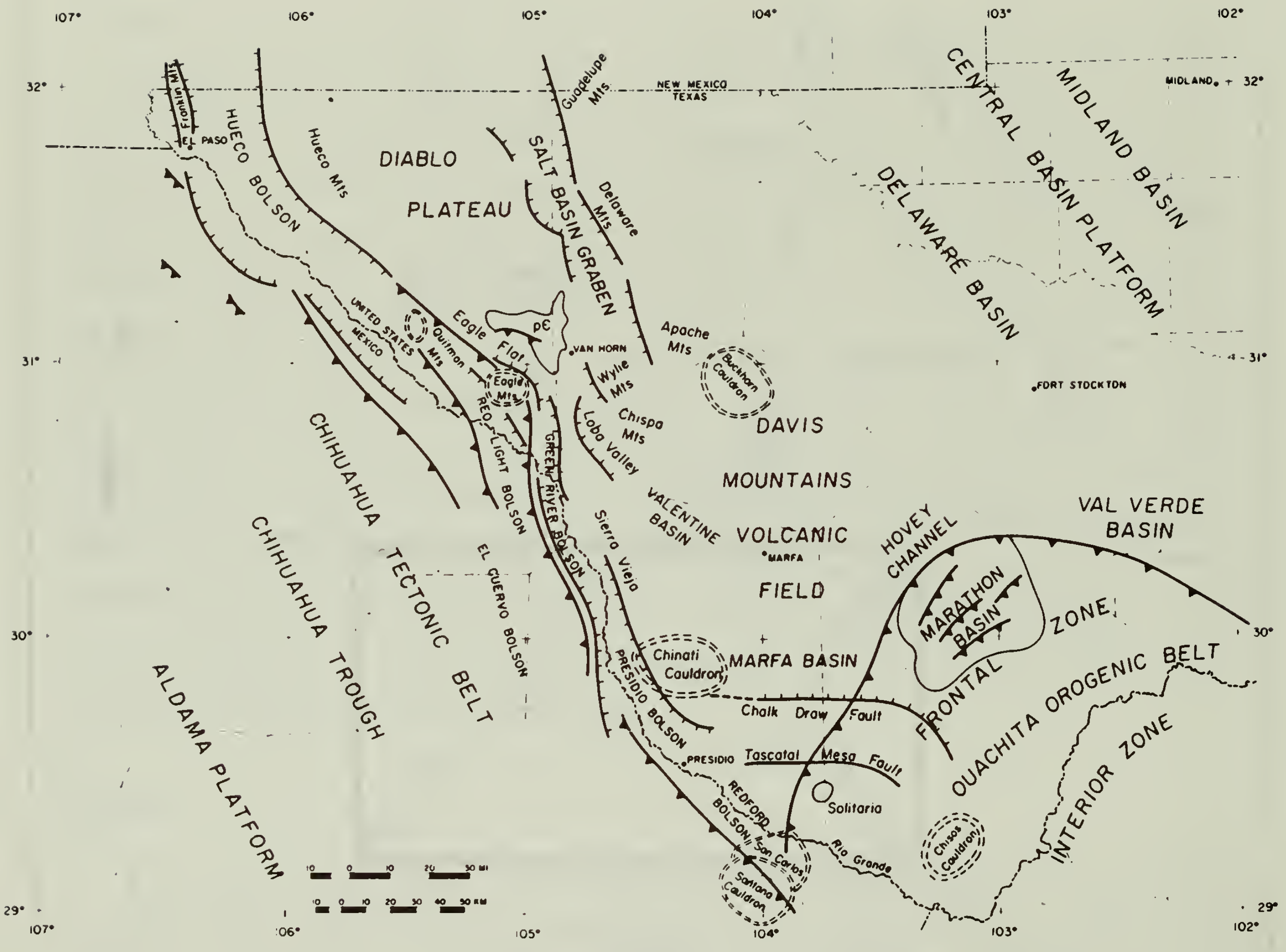


Figure 3. Location of the major geologic features of the Rio Grande-Trans Pecos region. (from Keller and Peeples, 1985)

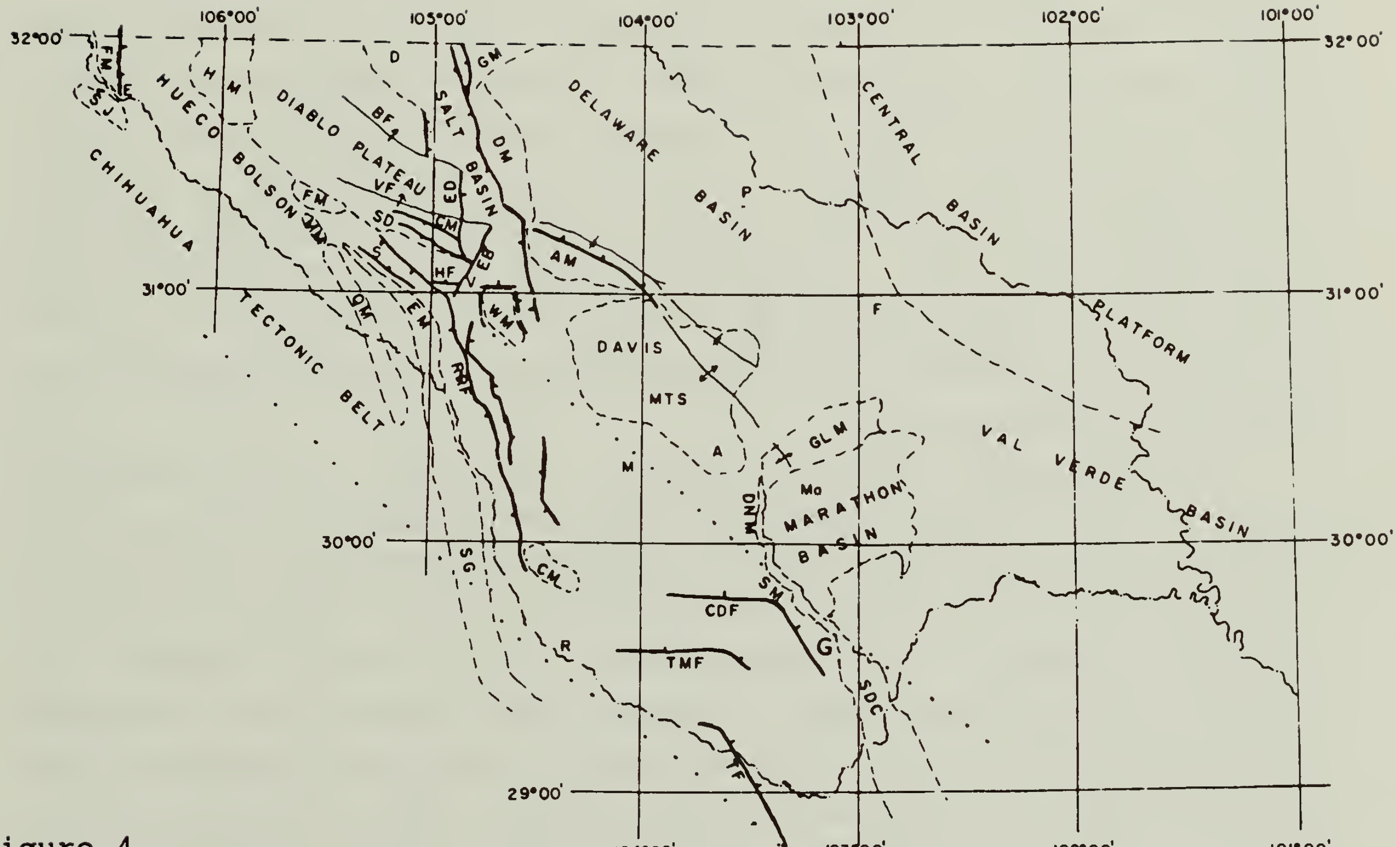


Figure 4.

Principal physiographic and tectonic features of Trans-Pecos Texas. Pecos River forms eastern boundary and the Rio Grande the western and southern boundaries of the area. Adjacent parts of Mexico, New Mexico, and West Texas are also included. Cities: E–El Paso, S–Sierra Blanca, V–Van Horn, D–Dell City, M–Marfa, A–Alpine, Ma–Marathon, P–Pecos, R–Presidio, F–Ft. Stockton. Mountain ranges: FM at New Mexico border–Franklin, HM–Hueco, FM–Finlay, MM–Malone, QM–Quitman, EM–Eagle, WM–Wiley, AM–Apache, DM–Delaware, GM–Guadalupe, CM–Chinati, GLM–Glass, DNM–Del Norte, SM–Santiago, SDC–Sierra Del Carmen, SG–Sierra Grande, SJ–Sierra Juarez. Flexures (monoclines): BF–Babb, VF–Victorio. G–Persimmon Gap. Faults, ticks on downthrown side: ED–East Diablo, CM–Cox Mountain, SD–South Diablo, HF–Hillside, EB–East Baylor, RRF–Rim Rock, CDF–Chalk Draw, TMF–Tascotal Mesa, TF–Terlingua. Modified from Wiley, 1970. Dotted lines mark two major lineaments seen on LANDSAT images. These are used as the north and south boundaries of the Texas Lineament

(from Muehlberger, 1980)

of the geology of the region, including igneous, sedimentary or stratigraphic, and structural topics. The scope of these projects have ranged from highly localized to regional in nature. The biology and archeology of the region has also been intensely studied.

This paper is concerned with previous efforts conducted on the tectonics and resultant sedimentation of the area. Numerous authors have contributed on these and related topics over the past century. The opinions and conclusions of these geologists have varied greatly, with a certain amount evolving thought process taking place with each new research project conducted in the region. Due to the continual revision of the geologic interpretation of the Rio Grande-Trans Pecos region, this paper will concentrate on the latest research efforts available. Time constraints for the construction of this paper also make this a most viable research option. Hopefully, recent research will point out the essential theories of the earlier workers of the region, and therefore these will not be overlooked.

Papers concerned with the tectonics of the region, include excellent synopsis' of the tectonic development of Trans-Pecos Texas by Henry and Price (1985) and Price and Henry (1985). Dickerson (1980) studied the complete tectonic history of the region as it related to structural trends and specific structural elements. The tectonic history of the Texas Lineament was chronicled by Muehlberger (1980). Underwood (1980) and Reaser and Underwood (1980) discussed the tectonic history of the Eagle and Quitman Mountains in the northwest part of the study area. Clark (1984) and Brown and Handschy (1984) studied the tectonic history of northern Chihuahua, Mexico, and made comments on deposition related to the tectonics. Horak (1985) discussed the tectonic history of the region but focused on the Permian Basin. Hills (1985) dealt specifically with the structural history of the Permian Basin. King (1980) reported on the tectonic history of the Precambrian and the early Paleozoic. Font (1985) studied the genesis of the structural patterns of the Paleozoic on a regional basis. Goetz and Dickerson (1985) evaluated Paleozoic structures, but with an emphasis on the Majave-Sonora Megashear. Gries (1980) and Handschy (1984) reported on the tectonics of northeastern Chihuahua, Mexico, with an emphasis on the Mesozoic. Dickerson (1985) documented the Mesozoic tectonic development of the study area, including comments on syntectonic sedimentation. Cobb and Poth (1980) studied the Laramide and Basin and Range structural features north of Big Bend. Muehlberger and Merritt (1985) concentrated on the

Cenozoic extensional tectonics of the Big Bend area.

Concerning syntectonic deposition, the following works proved useful. Reynolds (1985) and Brooker (1985) studied Precambrian thrusting and syntectonic deposition. The Precambrian sedimentary geology of the Van Horn area was discussed by Davidson (1980) and Denison (1980). Edwards (1980) detailed the Precambrian and early Paleozoic sediments of Tumbledown Mountain, northwest of the study area. DeMis (1985), Duncan (1985), and Tauvers (1985) deal with the orogernic activity and syntectonic sedimentation of the late Paleozoic in the Marathon area. Ross and Ross (1985) also dealt with late Paleozoic sedimentation as related to tectonic activity. The stratigraphy of the Big Bend National Park, from the Paleozoic to recent was discussed by Maxwell, et al (1967), Maxwell (1968), and Maxwell and Dietrich (1972). The early Cretaceous syntectonic deposition of the Yucca Formation was studied by Campbell (1980). Bilodeau (1978) also studied early Cretaceous syntectonic sedimentation on the northwestern end of the Chihuahua Trough. Weidie et al (1980) studied late Cretaceous syntectonic sedimentation in northeastern Mexico. the late Cretaceous synorogenic sedimentation in the Maverick Basin was reviewed by Weise (1980). Belcher (1975) conducted an excellent study of the evolution of the Rio Grande, from which much information on syntectonic deposition since Laramide times was derived. Winker (1981, 1982) discussed pulses of Cenozoic syntectonic sedimentation along the entire Gulf Coast Basin. Stevens and Stevens (1985) also studied Cenozoic deposition and presented a fine study on the history of bolson deposition in Trans-Pecos Texas.

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REGIONAL TECTONIC SETTING

The Rio Grande-Trans Pecos region, being situated in the south-central portion of North America, has been in a location that was either directly affected or was surrounded by a series of tectonic events that took place almost continuously since the Precambrian. In order to fully understand the localized tectonics of this region, and the resulting syntectonic sedimentation, it is necessary to relate the local deformational history to the regional tectonic framework, of which the area of study is an integral part.

PRECAMBRIAN

One of the earliest known tectonic events in North America that affected the Rio Grande-Trans Pecos region was a rifting event at approximately 1,500 Ma. Dickerson (1980) reiterates the theory that this event resulted from the separation of the North American and the Siberian cratons, and is responsible for the position of the southwestern edge of the North American craton. Arkosic and quartzose clastic sedimentation was a product of this early tectonic event.

The Grenville Orogeny was the next event to have affected the region. This occurred in the Precambrian, from approximately 1,380 Ma to 1,000 Ma (Goetz et al, 1985). According to Horak (1985), this orogenic event resulted from northwest-southeast plate convergence, and superimposed a northeast-southwest structural trend. Goetz et al (1985) asserts that Precambrian crust was accreted and sutured to the North American craton along this structural trend. Muehlberger (1980) reasserts the theory that west-northwest trending crustal lines of weakness were established at this time, and would be rejuvenated periodically thereafter (e.g. Texas Lineament). Horak (1985) postulated the closing of a wedge shaped ocean with this collision. This may have represented the formation of proto-Pangaea (Goetz et al, 1985).

Another major tectonic event affected the area of study during the late Precambrian (850 Ma), when the perimeters of the North American craton underwent rifting, forming the geosynclinal basins of the early Paleozoic (Horak, 1985). This event may have enhanced the west-northwest trending

crustal discontinuities, establishing a set structural grain that has persisted ever since.

POST-PRECAMBRIAN TECTONIC FRAMEWORK

From late Precambrian until Triassic time the Rio Grande-Trans Pecos region was situated in an episodically active transform coastline, bounding the southern edge of North America (Goetz et al, 1985). The position of this transform boundary appears to have been coincident with the Mojave-Sonora Megashear as shown in Figure 5. This transform zone appears to have been one of the crustal discontinuities that was established in late Precambrian time. According to Goetz et al (1985), no continental land mass was implaced south of this boundary until Triassic or Jurassic time. Dickerson (1985) asserts that this transform boundary underwent strike-slip deformation periodically from Precambrian through middle Mesozoic, and possibly laramide time, as a result of alternating periods of compression and extension.

LATE PRECAMBRIAN-EARLY PALEOZOIC

From late Precambrian to middle Devonian, this transform margin was situated between the passive margins of western and southern North America (Ross et al, 1985). Subduction was taking place along the eastern margin of the craton which resulted in the collision of Europe with northeastern North America. According to Ross et al (1985), this tectonic activity forced the western edge of the continent westward resulting in renewed tectonic activity along the western margin, as activity waned along the eastern margin. From the time of the Antler Orogeny (late Devonian) until early Mississippian time the transform margin southwest of the area of study served as the connection between the tectonically active western margin of North America and the passive eatern margin of North America. During this period, the Antler Orogeny which was taking place along the western margin of the North American craton had no discernable effect on the Rio Grande-Trans Pecos region.

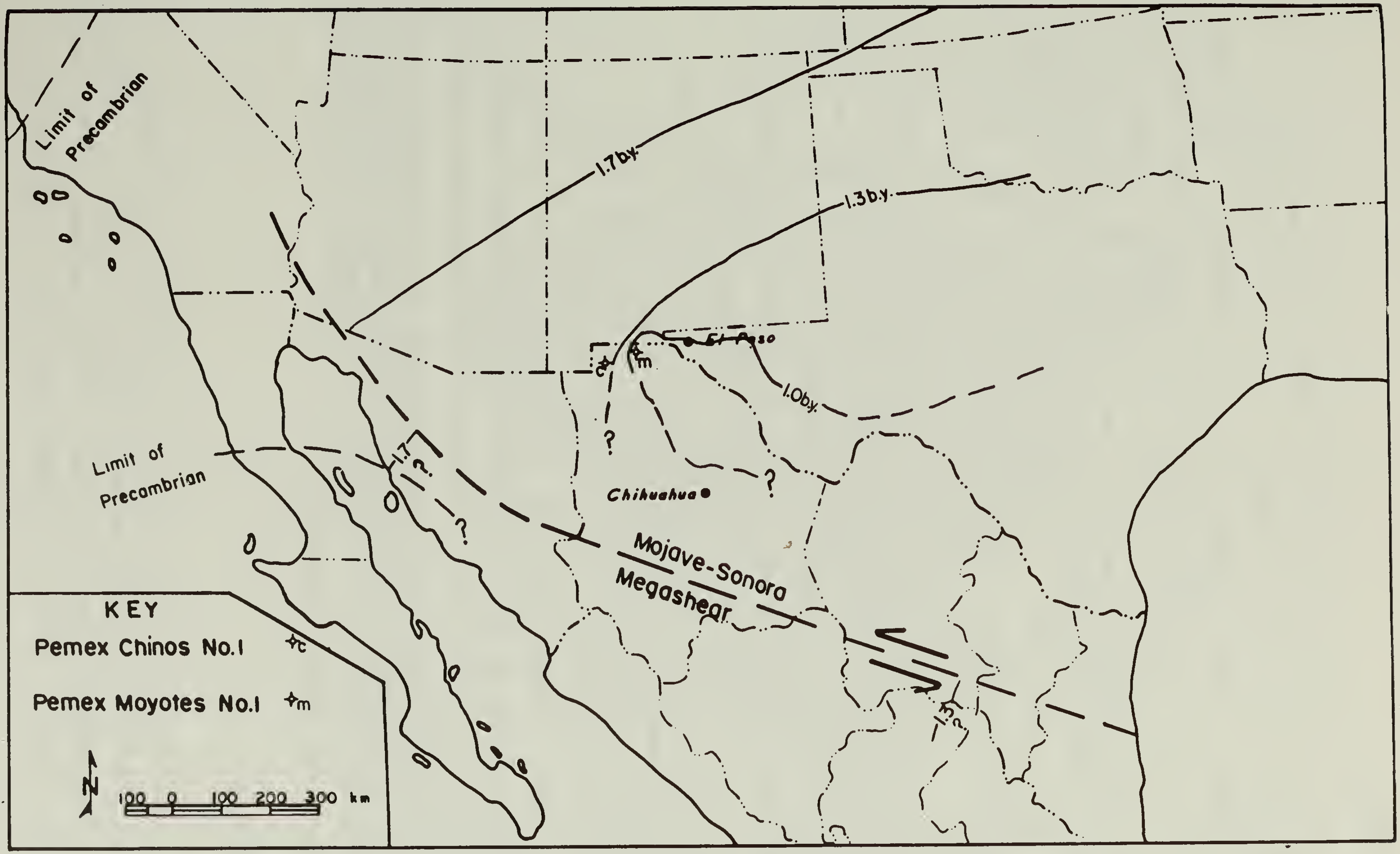


Figure 5. Position of the Mojave-Sonora Megashear bounding the southwestern edge of the North American craton. Precambrian isochrons are also shown. (from Brown and Handschy, 1984)

LATE PALEOZOIC

The next major tectonic event to affect the region occurred during the late Paleozoic (Mississippian-Permian), when the previously passive eastern margin of North America transformed into an active margin. This event formed an orogenic belt along the southern and eastern margins of North America. This episode of tectonic activity is related to the northwest-southeast convergence of the southern and eastern margin of the North American plate with the South American, African, and European plates which eventually formed Pangaea (Henry et al, 1985, Horak, 1985). This event resulted in the development of the Ouachita-Marathon structural belt, the Appalachian trust belt and the foreland deformation of the ancestral Rocky Mountains (Figure 6). Horak (1985) cites Graham et al (1975) and Ross (1979) with the conclusion that closure of the proto-Atlantic Ocean and proto-Gulf of Mexico began during the Devonian in the northern Appalachian Mountains and rotated with time to the southwest, culminating during the Permian in the Marathon region. Skinner (1979 and personal communication) refutes this theory, asserting that deformation along the east coast started in the southern Appalachian Mountains and migrated northward with time, culminating during early Permian (Wolfcampian) time. Therefore it seems that continental collision may have occurred first in the southeasternmost part of the continent and migrated both northward along the east coast and westward along the southern coast of North America with time. Tauvers (1985) reports that the stratigraphy of the Marathon area is essentially the same as that of the Ouachita area of Oklahoma and Arkansas, but the thickness of the section is less than half. Structural style is also analogous, although less intense in the Marathon area. According to Goetz et al (1985), the lingering effects of the Antler Orogeny to the west may have served as a buttress along the Mojave-Sonora Megashear, thus permitting the intensity of the Ouachita deformation.

EARLY MESOZOIC

The continental land mass south of the Mojave-Sonora Megashear began to accrete to the North American continent during the Triassic or Jurassic as a result of the Sonoma Orogeny, which was occurring southwest of the study area (Goetz et al, 1985). Brown et al (1984) asserts that initiation of the

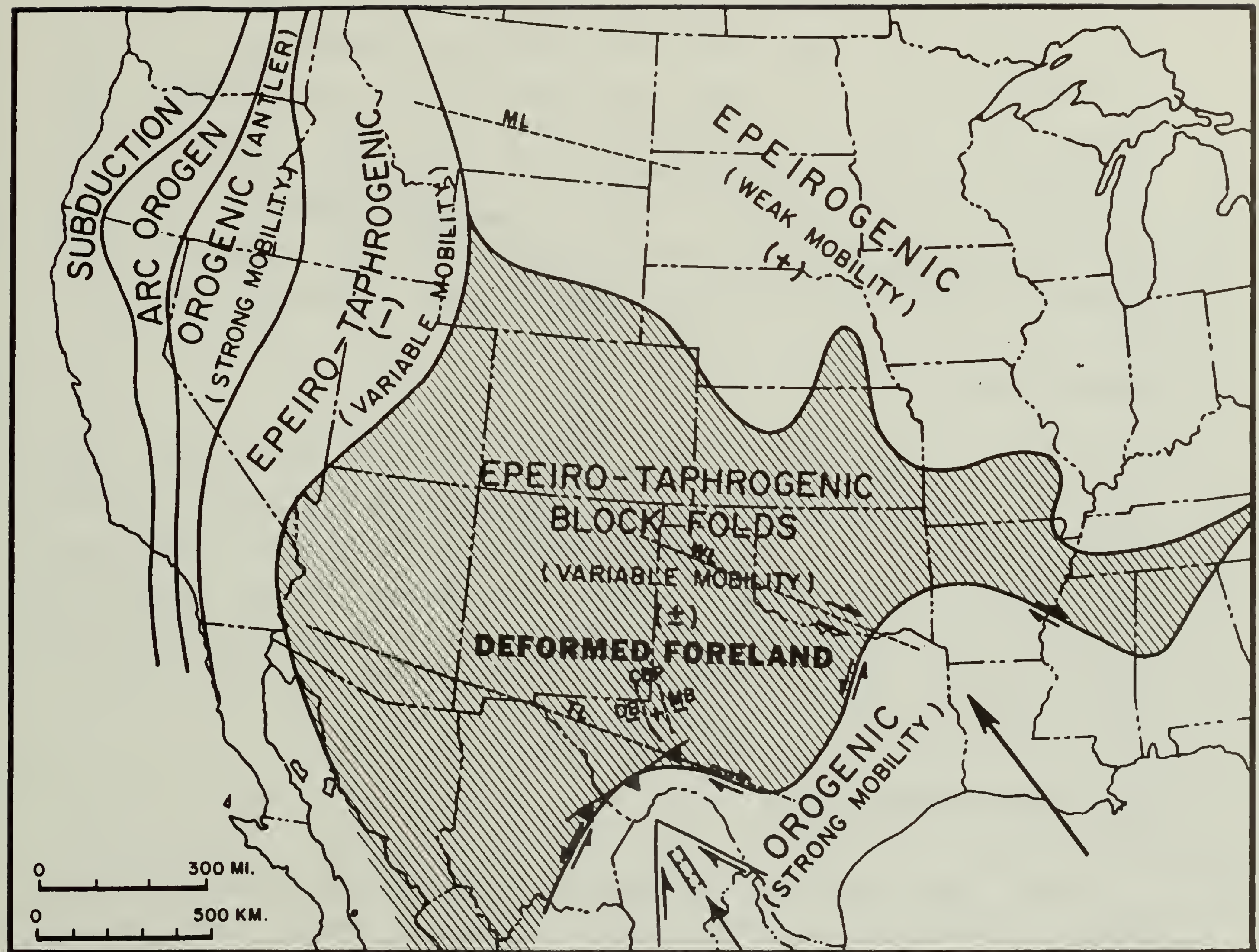


Figure 6.

Late Paleozoic paleotectonic style (300–260 Ma) illustrates principal horizontal stress direction, fundamental lineaments and extent of deformed foreland. TL = Texas Lineament, WL = Wichita Lineament, ML = Montana Lineament, DB = Delaware Basin, MB = Midland Basin, CBP = Central Basin Platform. The first significant evidence of tectonism from a southeasterly source occurs in the Early Pennsylvanian based on the distribution of rocks beneath the pre-Strawn unconformity. Final collision and convergence is based on the early Wolfclamp (Early Permian) date of thrusting in the Marathon orogenic belt and the development of the principal structural elements of the Permian Basin.

(from Horak, 1985)

circum-pacific orogenic system occurred in Triassic time, implying the suturing of this land mass may have been an early expression of the Laramide compressive event, which would later become very pronounced immediately west of and including portions of the study area. Supporting this idea, Hanschy (1984) reports that there is evidence of fold and thrust deformation with northeastward transport at approximately this time southwest of the study area at Sierra del Cuervo, Chihuahua. There is evidence that this event rejuvenated left lateral movement along the Mojave-Sonora megashear which apparently offset the Ouachita fold and thrust belt as shown in Figure 7 (Handschy, 1984).

MIDDLE MESOZOIC

During the middle Mesozoic, in addition to being situated northeast of the reactivated transform movement along the Mojave-Sonora megashear, the Rio Grande-Trans Pecos region was located northwest of the opening of the current Gulf of Mexico basin (Henry et al, 1985). These regional tectonic elements had a direct effect on the formation of the Chihuahua Trough and the ancestral Rio Grande Embayment during the Jurassic. Dickerson (1985) termed the nature of this type of deformation as "transtensional".

LATE MESOZOIC-EARLY CENOZOIC

Horak (1985) concludes that Laramide tectonics began along the western margin of North America during the middle Jurassic, however stress was not transmitted upon the foreland portion of the continent, which includes the Rio Grande-Trans Pecos region, until a period of more intense plate convergence near the end of Laramide deformation. The orogenic activity from late Mesozoic to early Cenozoic time resulted from east-west convergence and subduction of the Pacific (Farallon & Kula) plate to the west under the North American plate to the east (Figure 8). Compressive stress was oriented obliquely across the Mojave-Sonora transform zone, which still was undergoing left-lateral movement during the final development of the Gulf of Mexico. This resulted in what Dickerson (1985) termed as "transpressive" deformation in the Rio Grande-Trans Pecos region.

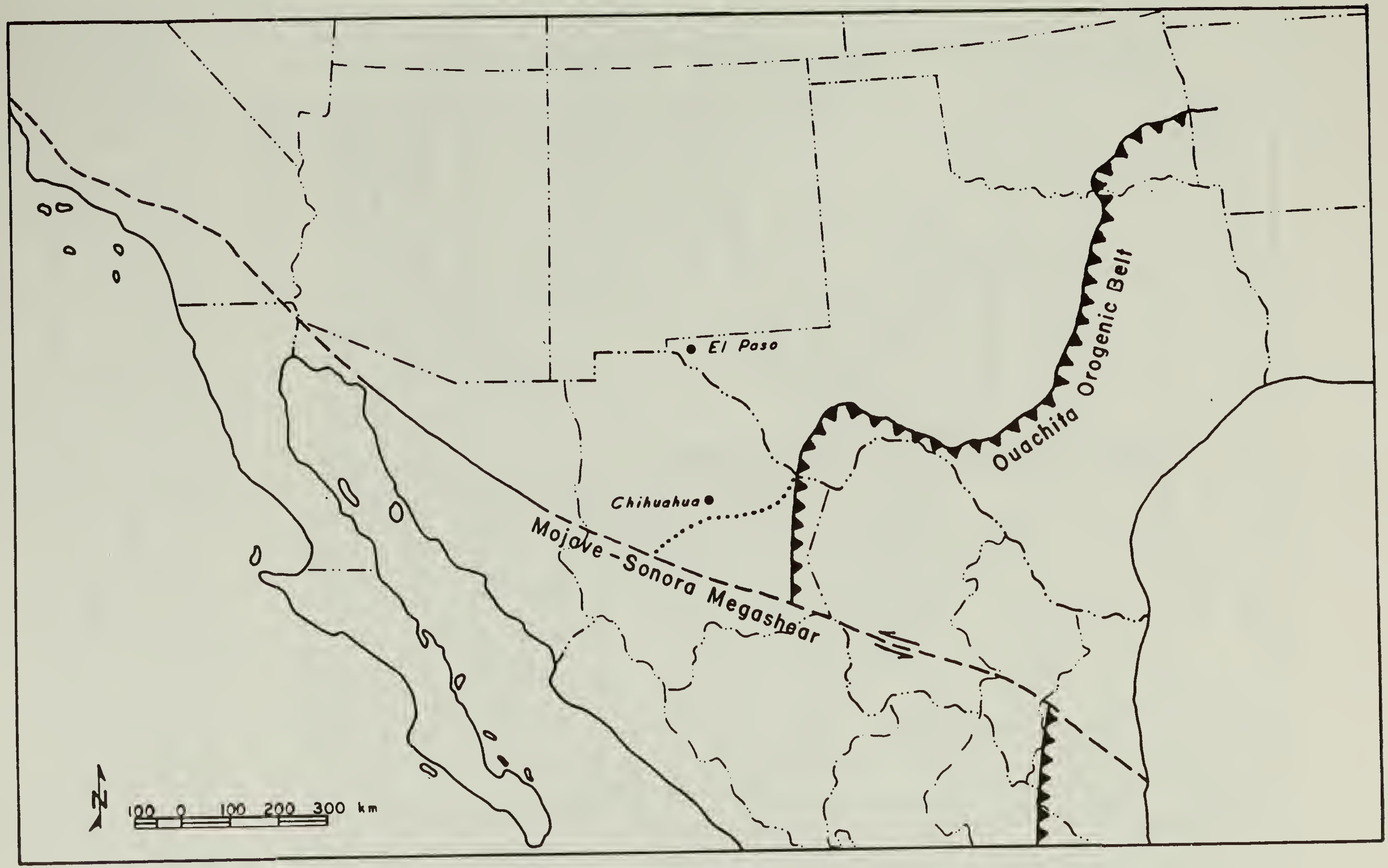


Figure 7. Relationship between the Ouachita-Marathon fold and thrust belt and the Mojave-Sonora Megashear illustrates the early Mesozoic left-lateral movement which took place in response to compression from the southwest and accretion of the Mexican land mass south of the megashear to North America (from Handschy, 1984)

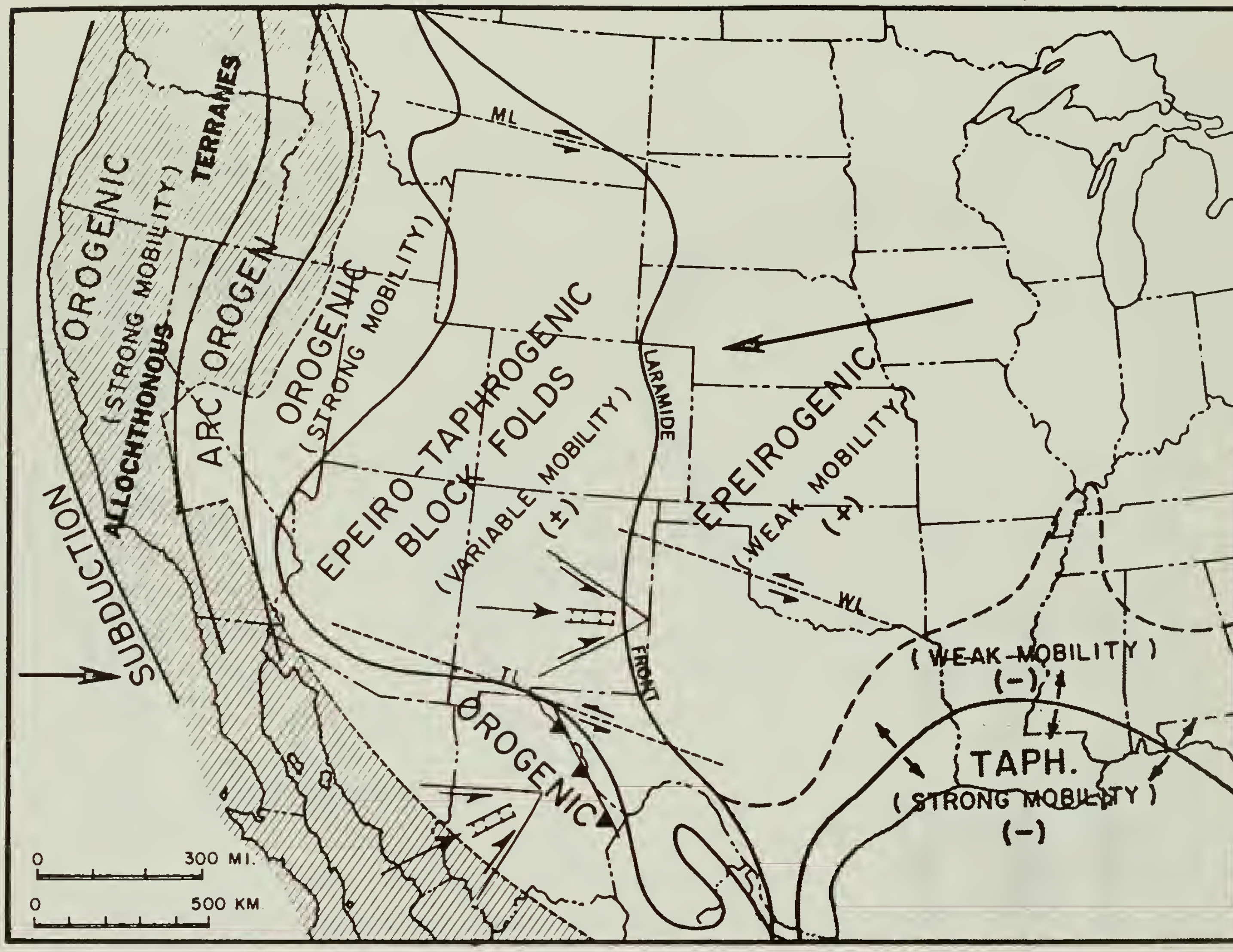


Figure 8. Paleotectonic style during the Laramide compressive event (80-50 Ma), resulting from convergence and subduction of the Pacific plate to the west under the North American plate to the east. Motion vectors are shown, illustrating a principle horizontal stress direction from the west and southwest. (from Horak, 1985)

LATE CENOZOIC

The convergent boundary along the western edge of North America changed to a transform boundary during the middle Cenozoic. This resulted in the west/northwest-east/southeast extensional deformation of the Basin and Range Province (Henry et al, 1985). Horak (1985) discussed the nature of this extensional deformation and illustrates the theory in Figure 9. Once again the regional tectonic regime rejuvenated strike-slip movement (right-lateral) along the shear fault systems transecting the region. This latest reactivation took place in order to compensate extension.

TECTONIC HISTORY AND SYNTECTONIC SEDIMENTATION OF THE RIO GRANDE-TRANS PECOS REGION

The Rio Grande-Trans Pecos region, as an integral part of the tectonic framework of the North American craton, has undergone a history of tectonic deformation directly related to that of the craton as a whole. Although related to this large scale orogenic history, the Rio Grande-Trans Pecos region has a unique local tectonic history. This smaller scale chronology of events has resulted in periodic syntectonic sedimentation corresponding to orogenic events that have taken place in the region. The stratigraphic position of these sediments provide a calendar of the deformational events that have occurred. The texture and composition of the various deposits defines the magnitude of the deformation, and from what direction the event occurred. Therefore, it is essential to study these deposits in order to better understand the geologic history of the region.

PRECAMBRIAN

Tectonic Activity

The Rio Grande-Trans Pecos region was affected by several episodes of tectonic deformation during Precambrian times. The earliest deformation is documented by Dickerson (1980) as a rifting event at 1,500 Ma. Henry et al (1985) discussed two or more coincident events at 1,000 Ma. This second episode of deformation took place as part of the Grenville Orogeny, considered

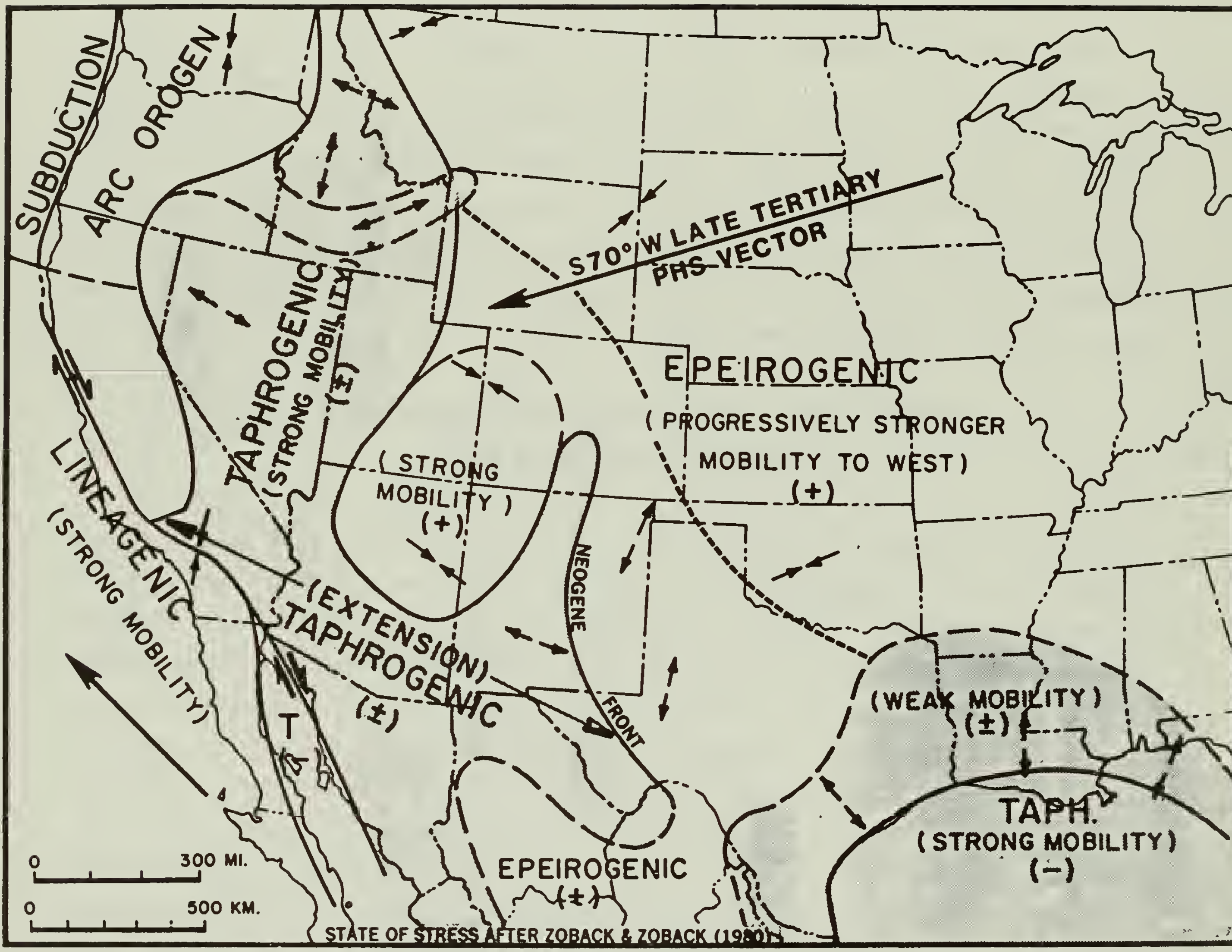


Figure 9. Late Cenozoic (25Ma-present) paleotectonic style illustrating extensional deformation across southwestern North America, resulting from transform movement along the western edge of the continent, as is shown by the plate motion vectors. (from Horak, 1985)

the major tectonic event of the Precambrian (Hills, 1985). The first phase of this event consisted of folding and thrusting of Carrizo Mountain sediments over the younger Allamore formation in a northward direction. At approximately the same time or possibly somewhat later (Reynolds, 1985), the Allamore Formation was thrust over the younger Hazel Formation. Figure 1 shows the stratigraphic position of these formations in relation to each other.

According to Font (1985) the tectonic activity during late Proterozoic time established lines of weakness in the basement of the Rio Grande-Trans Pecos region. These crustal discontinuities would become reactivated with later periods of tectonic activity, establishing a structural grain for the region, which persists to present times. Hills (1985) described the formation of these crustal discontinuities as the welding of the active tectonic zone to the North American craton.

Minor tectonic activity also occurred near the end of the Precambrian (Henry et al, 1985), with the displacement of the Hazel Formation along a left-lateral wrench fault, which trended west-northwest through the area. The Precambrian closed with a period of uplift which persisted until middle Ordovician.

Syntectonic Sedimentation

According to Dickerson (1980), the earliest syntectonic sediments in the area are the arkosic and quartzose clastic meta-sediments of the carrizo Mountain Group. These sediments are related to a rifting event at 1,500 Ma. Hills (1985) reported that erosion of a granitic terrain and deposition of sediments derived from that terrain accompanied the tectonic activity of the Grenville Orogeny at approximately 1,000 Ma. Also, during this episode of thrusting, the allochthonous rocks underwent erosion, transport, and subsequent redeposition. Evidence for this is clasts of the Allamoore Formation found in the younger Hazel Conglomerate (Dickerson et al, 1985, King, 1980). Reynolds (1985) describes the Hazel Formation as composed of coarse limestone conglomerates and fine-grained sandstones with poor sorting and angular clasts ranging up to boulder size. The sediments were deposited in an alluvial fan system (Davidson, 1980). Variation in clast size indicates a northward detrital transport direction, away from the tectonically active area to the south.

Near the end of the Precambrian, the Van Horn Sandstone (Figure 1) was deposited on a deeply eroded surface, following uplift and erosion of the Hazel Formation (Henry et al, 1985). According to Reynolds (1985), the Van Horn is a red arkosic sandstone deposited in coalescing alluvial fans with a southerly transport direction. Another period of erosion occurred from latest Precambrian to Ordovician, following a period of uplift. This resulted in an erosional surface on which Paleozoic rocks were deposited.

PALEOZOIC

Tectonic Activity

During the early Paleozoic only minor epiorogenic movements took place, with accompanied uplift. According to Henry et al (1985), the major Paleozoic deformational event to affect the study area occurred during the later part of Paleozoic, producing the Ouachita-Marathon fold and thrust belt. The position of this orogenic belt is illustrated in Figure 3.

The Ouachita event began with uplift during the Mississippian and culminated during the Permian with continued uplift, folding and thrusting. King (1980) and DeMis (1985) documented the deformation as a two phase event. First, as the Ouachita event began, during the Mississippian, a foredeep basin (Marfa and Val Verde Basins) developed to the north and west in front of the spreading thrust belt. Secondly, during late Pennsylvannian-early Permian, the sediments which had accumulated in the early foredeep basin were included in the thrusting as the belt spread northward to its present implacement position. Hell's Half Acre of the Marathon Basin is an example of this later type of deformation. Figure 10 illustrates the magnitude of deformation at Hell's Half Acre. Ross et al (1985) affirms this later phase of deformation as is illustrated in Figure 11. The location of late Paleozoic faulting in the study are is shown in Figure 12. In summary, Ross (1985) describes the Ouachita event as extremely complex in that uplifts and basins were continually being formed, destroyed, and reformed, including basins becoming uplifts, and uplifts becoming basins.

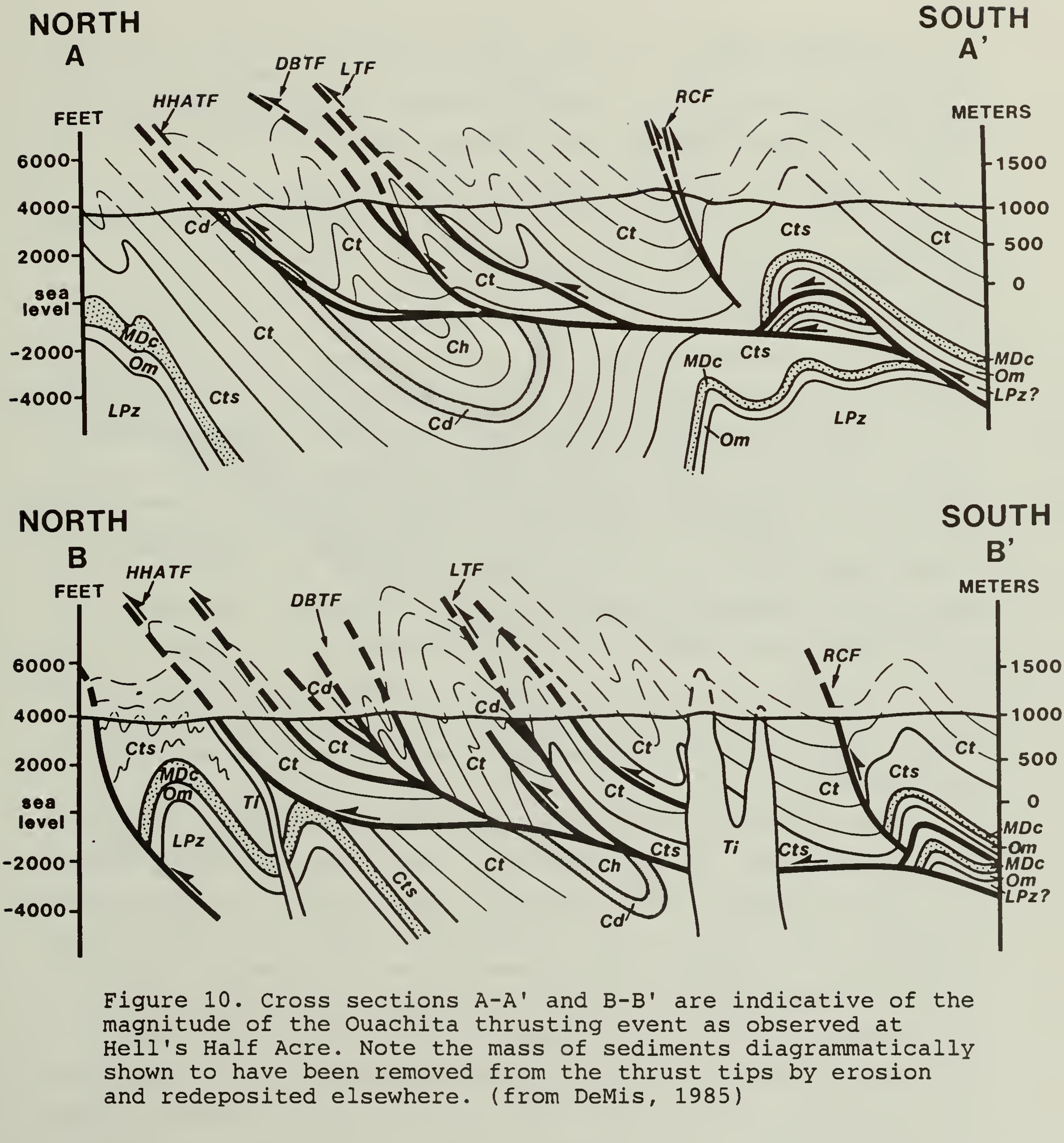


Figure 10. Cross sections A-A' and B-B' are indicative of the magnitude of the Ouachita thrusting event as observed at Hell's Half Acre. Note the mass of sediments diagrammatically shown to have been removed from the thrust tips by erosion and redeposited elsewhere. (from DeMis, 1985)

Syntectonic Sedimentation

Muehlberger (1980) states that several epiorogenic movements during the early Paleozoic produced unconformities, indicating that some erosion had taken place with each movement. Possibly the conglomeratic beds of the Ordovician Maravillas Formation (Figure 1) are an example of deposition related to one of these minor tectonic events.

As Quachita deformation began during the Mississippian, the foredeep basin, that developed in front of the advancing thrust belt to the south, became the depocenter for syntectonic sedimentation. A thick sequence of Upper Paleozoic flysch and molasse sediments, starting with the Tesnus Formation, including the Haymond Formation, and culminating with the Gaptank Formation (Figure 1), subsequently filled the foredeep basin (Dickerson et al, 1985, Ross et al, 1985). Duncan (1985) describes the Tesnus and Haymond formations as thick turbiditic sandstone and shale sequences exhibiting numerous soft-sediment deformational features. The depocenter of the foredeep basin continually migrated to the north (Hills, 1985), with the northward spreading of the thrust belt. As the belt spread northward, the early syntectonic deposits were eventually included in the thrusting. Consequently the allochthonous rocks underwent erosion and redeposition. An example of this type of deposition is the basal conglomeratic member of the Gaptank formation containing clasts of the older Dimple Limestone, described by Ross et al (1985). Figure 10 illustrates the mass of sediments that were eroded from the advancing thrust tips.

Ouachita thrusting continued throughout the late Paleozoic. Ross et al (1985) contends that late Pennsylvannian to early Permian sediments, including the Gaptank Formation, were eventually thrust northward in the "Dugout Allochthon", resulting in a smaller Marfa Basin (Figure 11). The prolonged deformation was accompanied by continued erosion and syntectonic deposition. Goetz et al (1985) points out that the extremely thick late Pennsylvannian to early Permian sections that are present in the Presidio and Hueco Basins of West Texas and Mexico are indicative of the magnitude of uplift and erosion that took place. Clastics derived from the uplifts were the dominant sediment accumulating in the basins during this time. These deposits are commonly conglomeratic at the base and exhibit an angular unconformity with the underlying rocks (Henry et al, 1985). It seems that the repetitive nature of

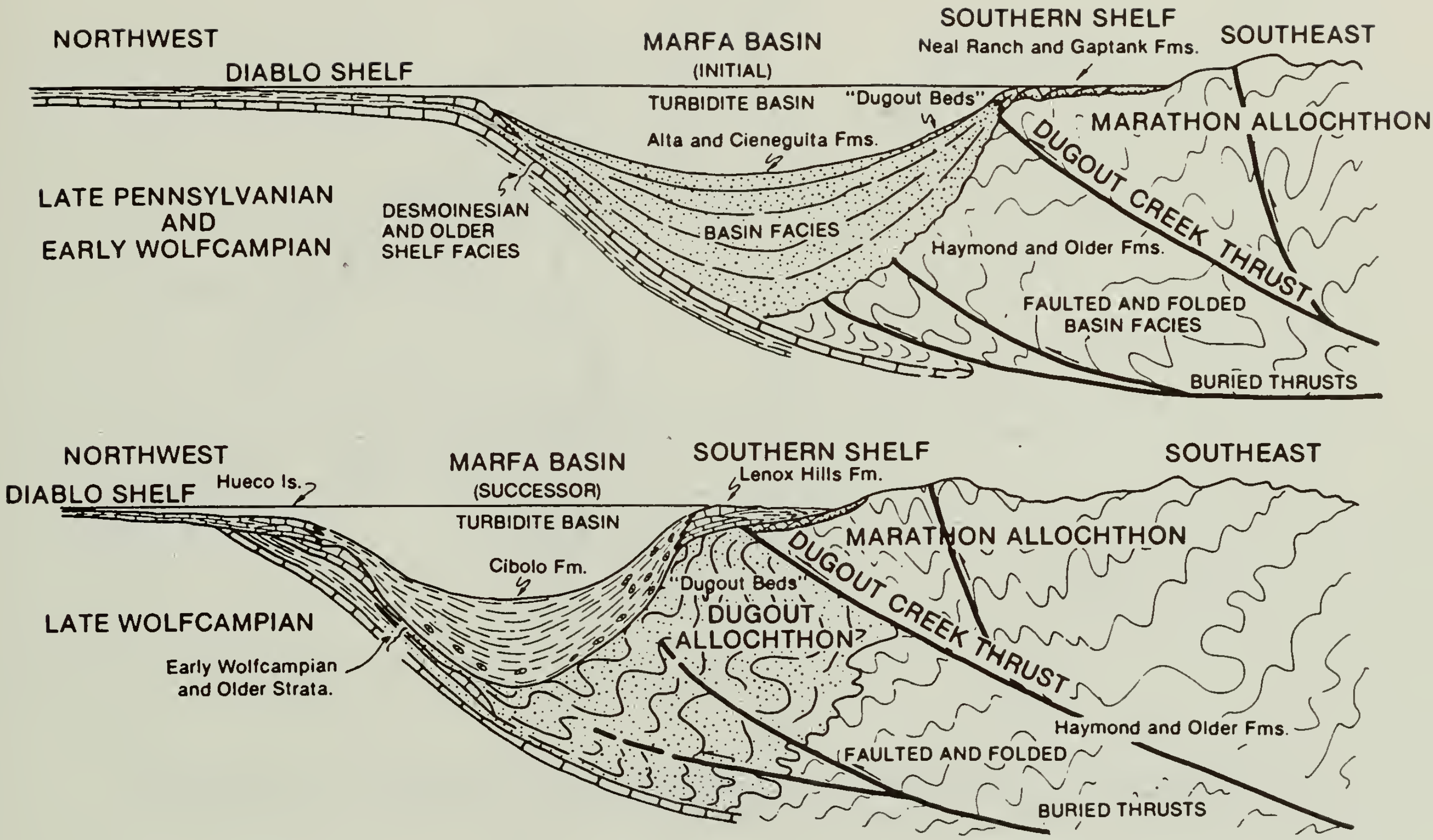


Figure 11. Cross sections illustrating early syntectonic deposits (Dugout Beds) that accumulated in the foredeep Marfa Basin, being included in a later phase of thrusting within the Dugout Allochthon. This later phase of thrusting reduced the size of the foredeep basin receiving syntectonic sediments, as the thrust belt spread northward. (from Ross and Ross, 1985)

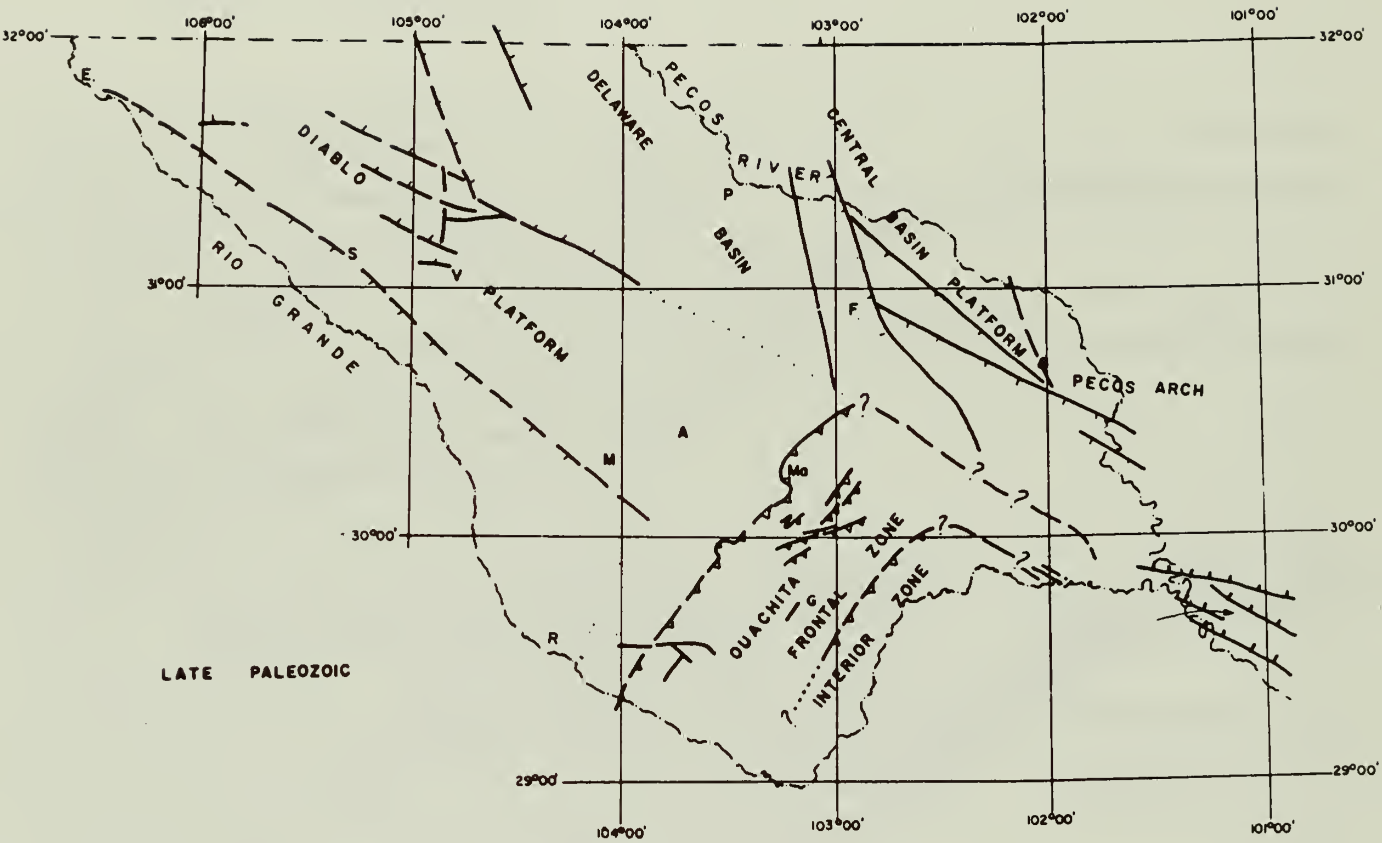


Figure 12. Location of late Paleozoic faults in the Trans-Pecos region. (from Muehlberger, 1980)

this event provided for the continual deformation and subsequent erosion of earlier syntectonic deposits as well as the earlier Paleozoic and Precambrian rocks.

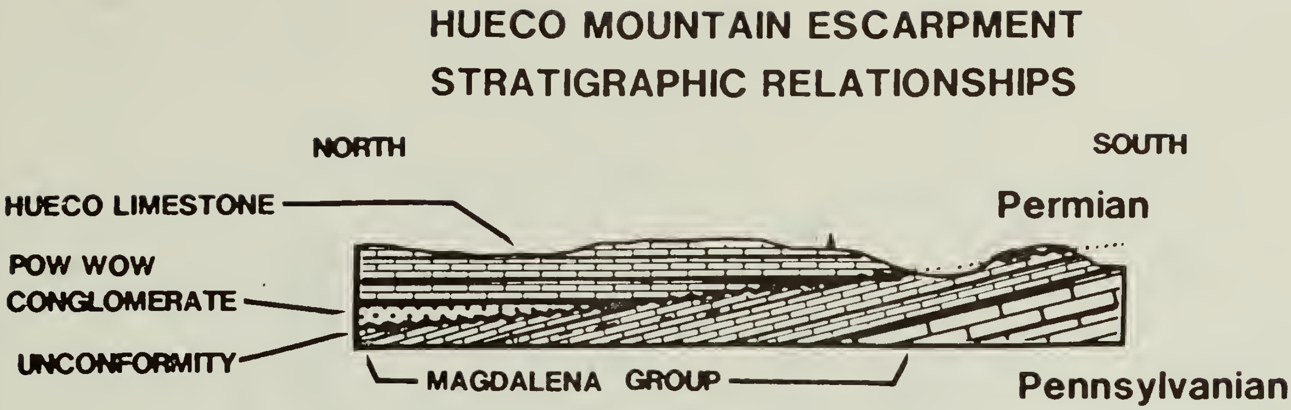
The arkosic conglomeratic sandstone of the Wolfcampian Powwow Formation (Figure 1) is an example of a late phase of syntectonic deposition, related to the Ouachita event. Figures 13 and 14 illustrate the alluvial fan complex interpreted to be the depositional environment of the Powwow in the Hueco Mountains, northwest of the study area. In the Miller Bros., #1 Thomas 139 well in Presidio County, the Powwow is unconformably overlying the Precambrian Van Horn Sandstone (Pearson, 1985). This indicates the magnitude of the erosion that took place associated with the Ouachita event. The entire Pre-Permian Paleozoic record section has been removed at this locale!

MESOZOIC

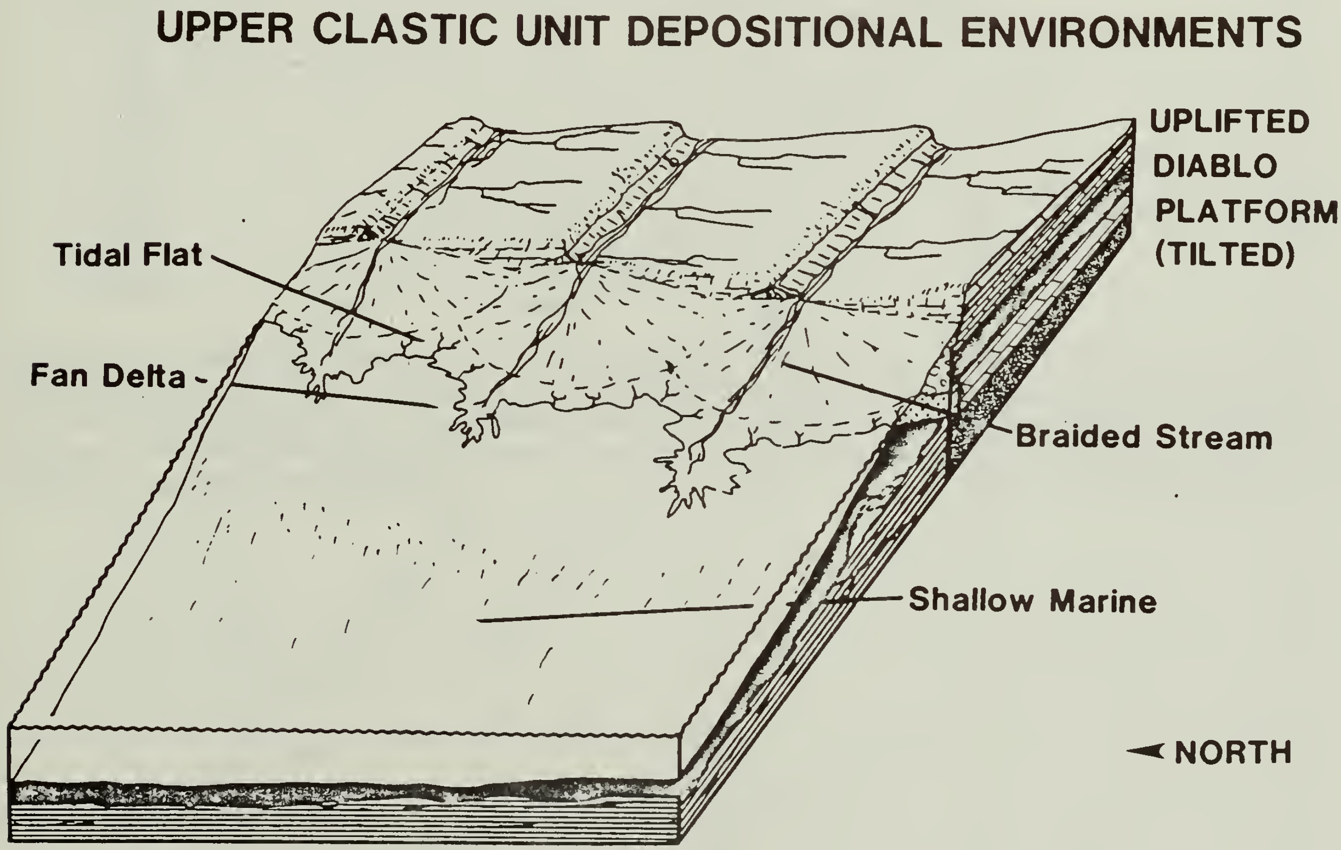
Tectonic Activity

During early to middle Mesozoic, the Chihuahua Trough and the ancestral Rio Grande Embayment were formed west and east of the study area by large scale normal faulting. The faulting was related to regional tectonic activity along the Mojave-Sonora megashear and the opening of the Gulf of Mexico (Dickerson, 1985). The deformation forming the Chihuahua Trough is described by Dickerson (1985) as "transtensional". The location of related faulting in the Rio Grande-Trans Pecos region is shown in Figure 15. Figure 16 shows the relationship of the resulting Chihuahua Trough to the faulting along its northeastern margin. According to Weise (1980), the Rio Grande Embayment originated as an aulacogen associated with the rifting of Pangaea. The northwestern end of the embayment is divided into two sub-basins. The Maverick Basin of south Texas is separated from the Sabinas Basin of Mexico by the Salado Arch as shown in Figures 17 and 18.

Starting in late Mesozoic, tectonic deformation of the Laramide Orogeny affected the study area. The style of early Laramide deformation in late Cretaceous was primarily regional uplift without folding (Maxwell et al, 1967). Intensity of the deformation increased into the Cenozoic, closing the Chihuahua Trough. Weidie et al (1980) described a late Cretaceous tectonic depression in front of the eastward spreading Laramide orogenic belt, which likely represents



Field sketch from King, King, and Knight (1945) of the western escarpment of the Hueco Mountains showing the thick wedge-shaped Powwow Conglomerate (Wolfcampian).



Block diagram—depositional environments of the Upper Unit, Wolfcamp, Permian Powwow Conglomerate.

Figure 13 & 14. Cross-section and block diagram illustrate the lower Permian Powwow Conglomerate deposited as a coalescing alluvial fan complex, overlying disturbed Pennsylvanian beds. This episode of syntectonic deposition represents the final stages of Ouachita deformation in that the underlying disturbed Pennsylvanian Magdalena Group was deposited during an earlier stage of the event. (from Pol, 1985)

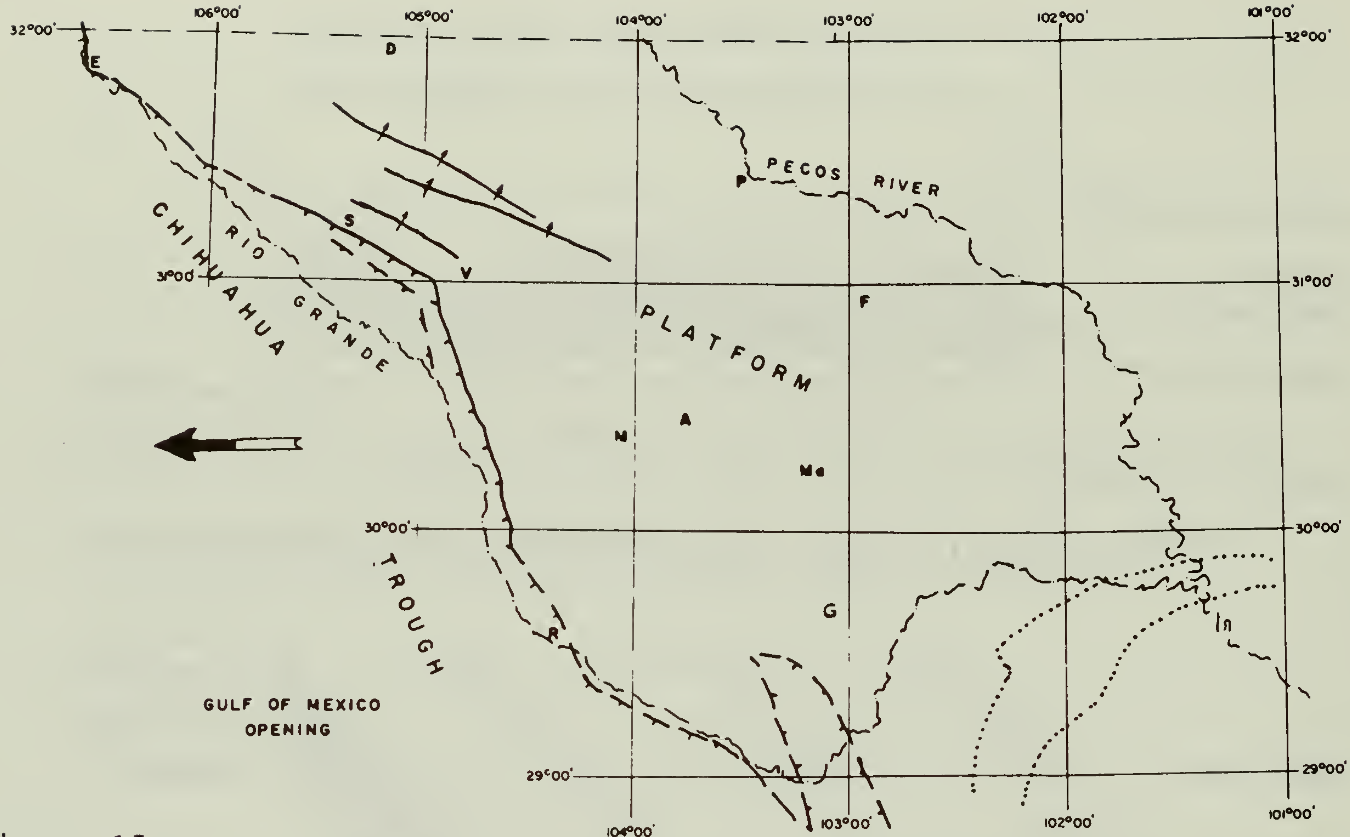


Figure 15.

Known mid-Mesozoic (Gulf of Mexico opening) faults. The principal feature is the prominent fault separating the subsiding Chihuahua Trough from the platform; reentrant into the south tip of the Big Bend is based on shapes of structures (tight asymmetrical folds) compared to those on either side. Monoclinal downwarps north of Sierra Blanca-Van Horn from King (1965). The dotted lines in the southeast corner of the map mark the boundaries of the mid-Cretaceous (Washita and Fredericksburg) reef. The landward kink lies along the northern border of the Texas Lineament

(from Muehlberger, 1980)

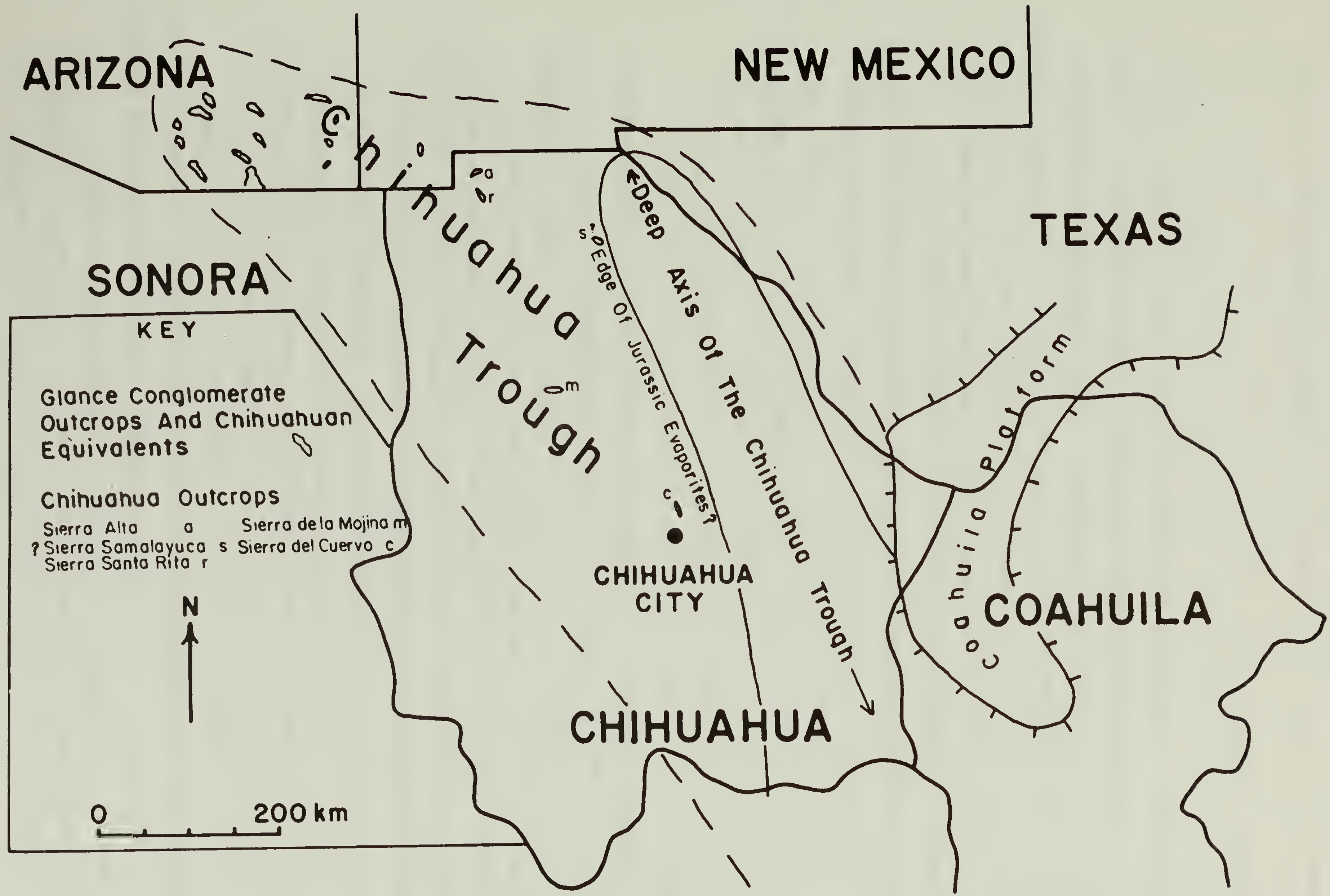


Figure 16. Location of the Chihuahua Trough southwest of the region of study. Recognized lower Cretaceous syntectonic conglomerates are shown west of the deep basinal axis. (from Brown and Handschy, 1984)

a remnant of the trough. This small basin is known as the Ojinaga Basin and is located immediately west of the study area, in Mexico (Figure 18).

Syntectonic Sedimentation

The Chihuahua Trough being the most proximal to the Rio Grande-Trans Pecos region of the two basins formed during the early to middle Mesozoic was the first basin to receive syntectonic sediments. Dickerson (1985) described the sedimentation within the basin as rapid and varied. The earliest deposits were directly related to the tectonic genesis of the basin. According to Brown et al (1984), Jurassic evaporites accumulated in the starved central portion of the basin, while conglomerates equivalent to the Glance Conglomerate (identified in southern Arizona and New Mexico by Bilodeau (1978) accumulated as alluvial deposits along the perimeter of the basin. Brown et al (1984) describes these conglomerates as typically containing clasts of underlying Paleozoic formations and Precambrian rock fragments within a reddish muddy to silty matrix, ranging in thickness from 3 to 3000 feet. Figure 16 shows the identified locations of these conglomerates, west of the deep basinal axis.

Examples of such alluvial deposits include the Jurassic La Casita Formation found on the west flank of the Chihuahua Trough near the Plomosas mining district of Mexico. Clark et al (1984) describes this unit as containing a basal conglomerate. East of the basinal axis such conglomerates have also been identified. Campbell (1980) describes the lower Cretaceous Yucca Formation, exposed in the Quitman Mountains, as a sequence of reddish conglomeratic silicaclastic strata deposited in response to uplift and erosion. These sediments exhibit cyclothems revealing an increase in conglomeratic character during periods of alluvial sedimentation in response to pulses of tectonic activity. A basal Cretaceous conglomerate containing boulders of upper Paleozoic rocks has also been identified southwest of Big Bend's Mesa De Anguila at the San Carlos Mine, near Manuel Benavides, Mexico by DeCamp (1985).

During the late Cretaceous, as early affects of the Laramide Orogeny uplifted the region and closure of the Chihuahua Trough began, erosion of older exposed rocks commenced. The earliest syntectonic sedimentation related to the Laramide event took place in the Ojinaga Basin (Weidie et al, 1980). Approximately 1000 feet of alluvial-deltaic sediments have been identified in this basin. Weidie et al (1980) also asserts that continental deposits

(redbeds) identified in the Big Bend area are a product of early Laramide tectonics. With the completion of infill of this shallow basin, the inception of an ancestral Rio Grande drainage system (Belcher, 1975, Weise, 1980) began to transport large volumes of tectonically derived terrigenous clastic sediments southeastward into the sub-basins of the Rio Grande Embayment (Figures 17 and 18). The dominantly clastic San Miguel, Olmos, and Escondido Formations represent syntectonic sediments that were deposited in the Maverick and Sabinas Basins at the end of the Cretaceous (Weise, 1980, Weidie et al, 1980). The position of this accumulation of clastic sediments overlying the lower Cretaceous carbonates is shown in Figure 1. According to Weise (1980), these sediments comprise the thickest accumulation of upper Cretaceous clastics present within the Gulf Coast basin. The thick sequence is indicative of the dominant influence of Laramide tectonics at the headwaters of the Rio Grande drainage system.

CENOZOIC

Tectonic Activity

The tectonic activity of the Laramide Orogeny continued with greater intensity into the Cenozoic. Henry et al (1985) described the event in the region of study as compressional tectonics resulting in east-northeast spreading thrust faulting, terminating along the eastern margin of the Chihuahua Trough (Figure 19). The stable Diablo Platform likely served as a buttress, limiting deformational extent. Cretaceous rocks were thrust along a de'collement zone rooted in the underlying evaporites (Gries, 1980). Cobb et al (1980) identified the reverse faulted monocline of the Santiago Mountains and Maravillas Ridge as typical Laramide compressional features located north of Big Bend National Park. Compressional folds developed behind the Thrustal fronts as is shown in Figure 20. This portion of the Laramide structural belt, trending through the Rio Grande-Trans Pecos region, has been termed the Chihuahua Tectonic Belt. Henry et al (1985) dates the major Laramide event in the Trans-Pecos region as late Paleocene.

According to Henry et al (1985), the compressional nature of Laramide tectonics culminated with Mid-Tertiary continental-arc volcanics. This terminated about 30 Ma with a transition to the tensional regime of Basin and

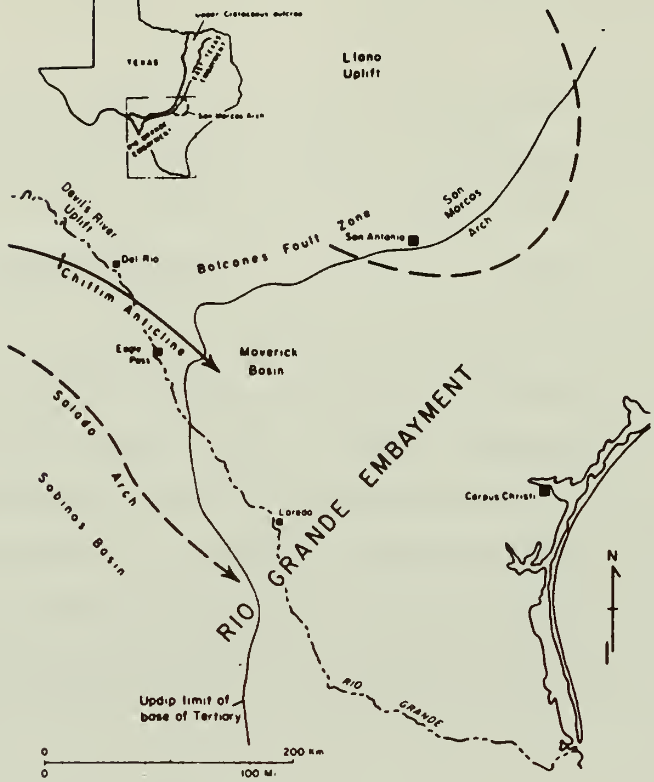


Figure 17. Location of the Maverick Basin and related structural elements on the northeast end of the Rio Grande Embayment. (from Weise, 1980)

Figure 18. Location of the Sabinas Basin and related structural elements on the northwest end of the Rio Grande Embayment. The late Cretaceous Ojinaga Basin is also shown west of the Big Bend region. (from Weidie et al, 1980)

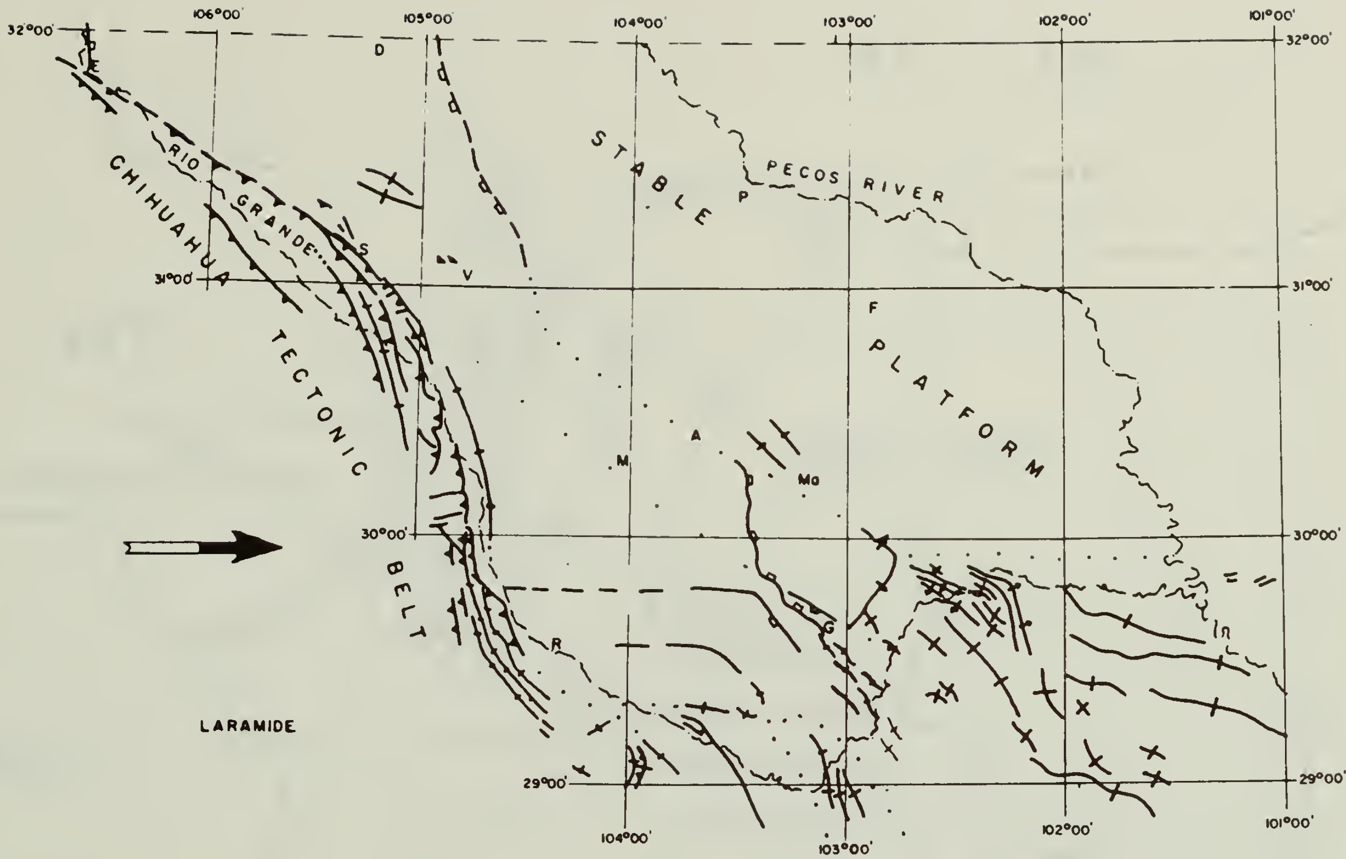


Figure 19. Location of Laramide age faults in the Trans-Pecos region, resulting from compressional or "transpressional" stresses applied to the region. The large arrow indicates the principle direction of thrusting. (from Muehlberger, 1980)

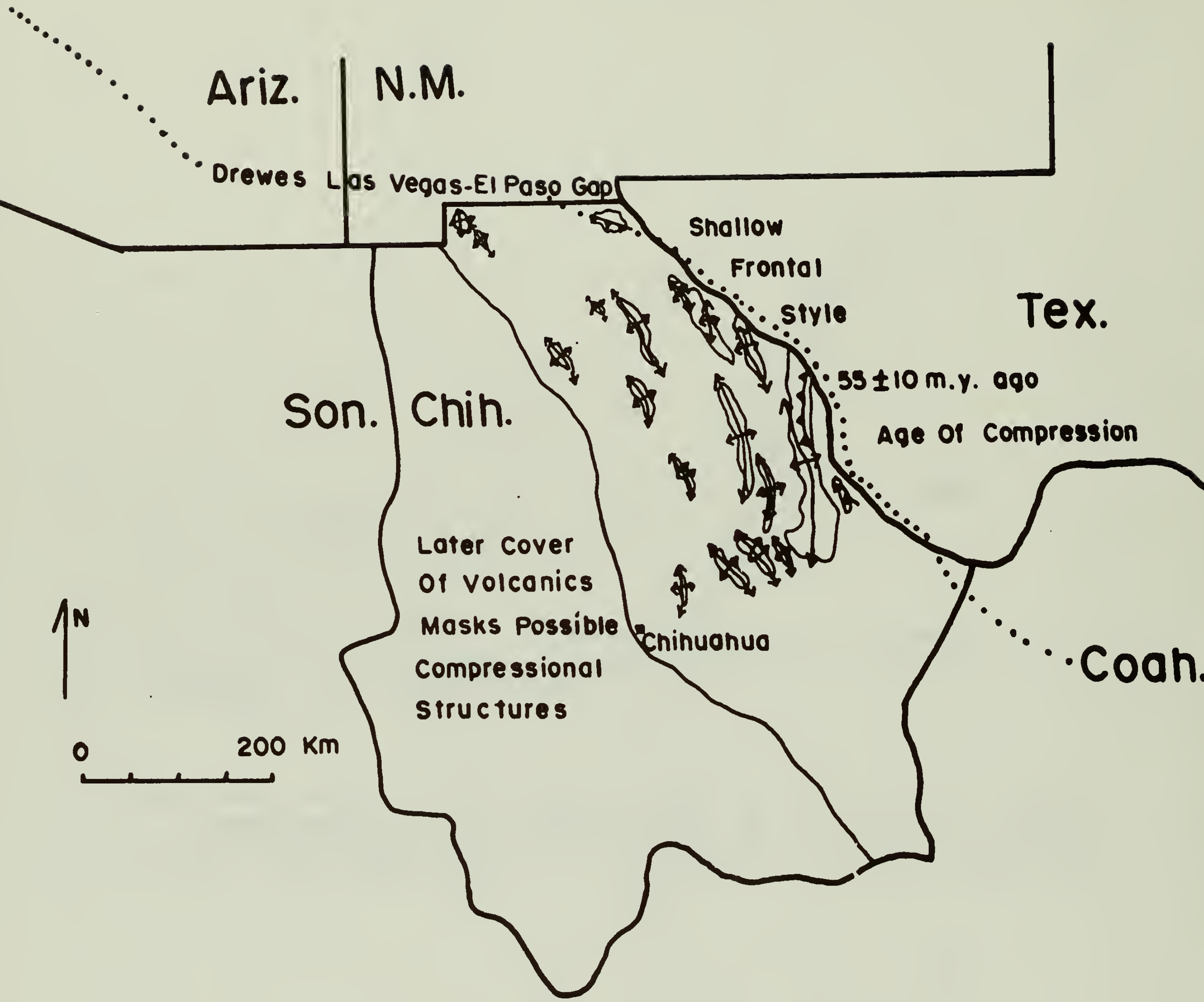


Figure 20. Location of Laramide compressional folds, which developed behind the front of the Chihuahua thrust belt. (from Brown and Handschy, 1984)

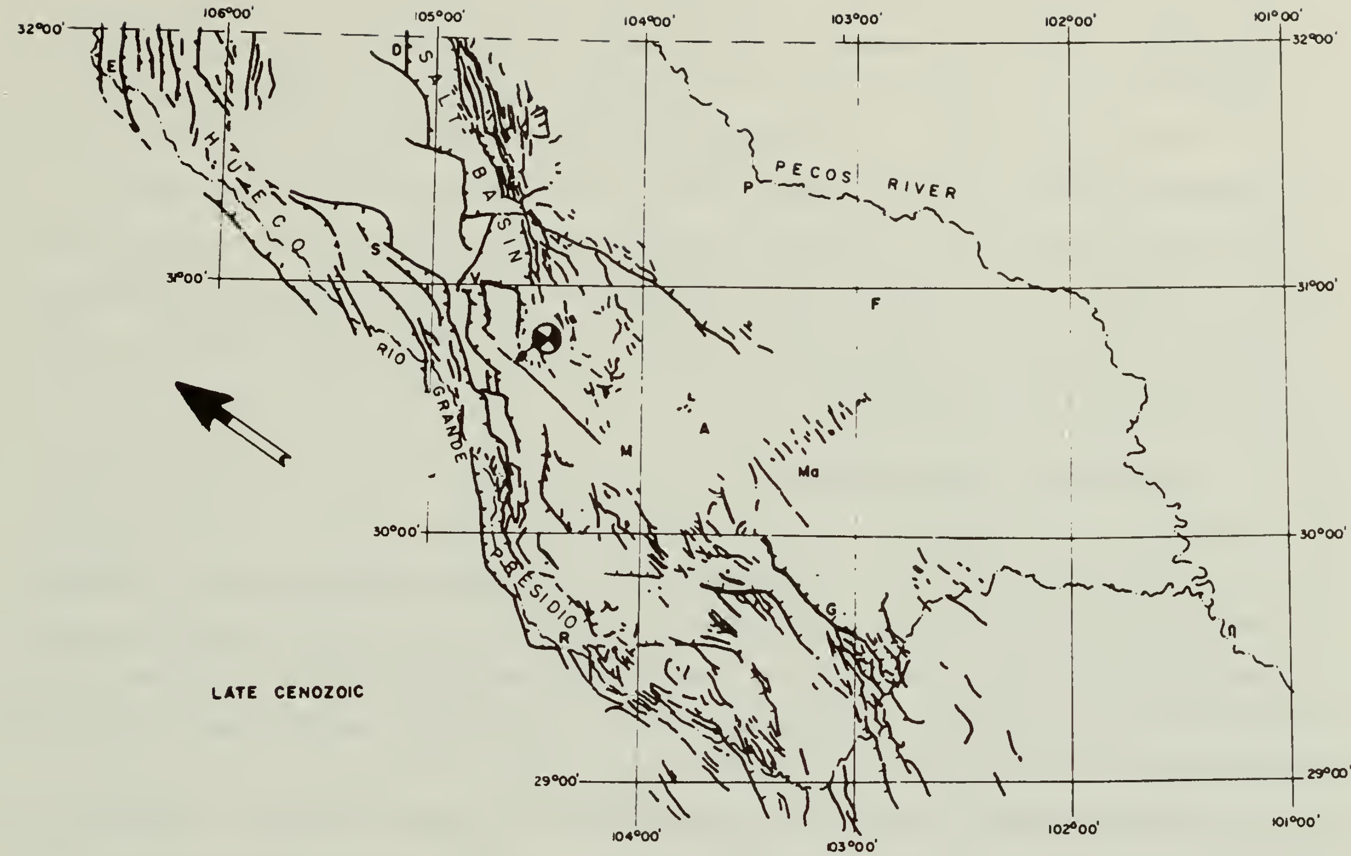


Figure 21. Location of late Cenozoic faults in the Trans-Pecos region, resulting from extensional or "transtensional" stresses applied to the region. The large arrow indicates the principle direction of movement. (from Muehlberger, 1980)

Range extension. Typical Basin and Range normal block faulting began in the Rio Grande-Trans Pecos region a few million years thereafter, and has persisted to a degee until the present. This extensional deformation has resulted in the development of a series of north-northwest trending intermontane basins that are bounded by either single normal faults or a series of parallel or en echelon faults. Figure 21 shows the location of Basin and Range faulting in the area of study. The horst block of Mesa de Anguila, the tilted fault blocks of the Sierra del Carmen, and the grabens near Boquillas Canyon in the Big Bend region are typical examples of this type of structure (Belcher, 1975, Muehlberger et al, 1985).

Syntectonic Sedimentation

As uplift, folding, and thrusting of the Laramide orogeny continued, syntectonic sedimentation took place in response to erosion of postive areas. Syntectonic sediments were either deposited along the flanks of uplifted areas, in local compressively formed basins, or were carried southeastward into the Rio Grande Embayment.

Pearson (1985) identifies a local deposit on the northeast flank of the Davis Mountains. He describes the basal Tertiary Jeff Conglomerate as a continental sandstone and coarse pebble conglomerate sequence deposited on a deeply eroded surface of the upper Cretaceous Taylor Marl.

The primary mechanism for transport of clastics eroded from tectonically positve elements of the region into the Rio Grande Embayment was the precursor of the modern Rio Grande drainage system (the Pecos, Rio Grande, and Rio Conchos Rivers (Figure 21). As stated earlier, this system originated in a somewhat different ancestral from with the tectonic activity of the Laramide Orogeny (Belcher, 1975, Weise, 1980). This drainage system was of primary importance to any syntectonic deposition which took place in response to Laramide or later tectonic events. The thick sequence of Tertiary sediments present in the Rio Grande Embayment of the Gulf coastal plain indicates that large amounts of sediment were for the first time transported to the southeast out of the Rio Grande-Trans Pecos region. This commenced with Laramide tectonics and has continued to present times. It seems likely that sediments were not only derived from the Rio Grande Pecos region but also from the headwaters of the Rio Grande to the northwest in New Mexico and Colorado

(Belcher, 1975). Belcher (1975) also presented excellent evidence that as regional uplift of the Laramide event took place, these river systems started to entrench themselves. This entrenchment would become much more pronounced as Basin and Range block faulting succeeded Laramide tectonics, as is typified by the great canyons present in the Big Bend region.

The first phase of syntectonic infilling of the Rio Grande Embayment was related to Laramide tectonics and began with the upper Cretaceous classic sequence identified in the Maverick and Sabinas basins and culminated with lower Eocene (upper Wilcox) delta systems (Weise, 1980, Winker, 1982). Figure 22 shows the location of these delta systems (Zapata, Duval, and Live Oak). A second phase of clastic infilling of the Rio Grande Embayment occurred during the Oligocene and was related to the extensional tectonics of the Basin and Range event. This started with a Vicksburg age (32 Ma) influx of volcanogenic sand and culminated with the large depocenter of the Frio age (28 Ma) Norias delta system (Winker, 1981, 1982). The Vicksburg and Frio depositional trends in the Rio Grande Embayment are shown in figure 22. Figure 23 is a cross-section illustrating the thickness of both the Laramide controlled Wilcox deposition and the Basin and Range controlled Frio deposition in the Rio Grande Embayment. Lesser episodes of clastic sedimentation occurred between these two major syntectonic episodes and have continued since the second episode. Figure 24 shows the sequence of Cenozoic depositional episodes recognized along the Gulf Coast. As discussed here, the major pulses are of a syntectonic origin.

Although significant quantities of tectonically derived sediments continued to be transported through the study area by the ancestral Rio Grande drainage system, the asymmetric intermontane basins formed by late Cenozoic Basin and Range extensional tectonics also received thick accumulations of locally derived clastic sediments eroded from the horst block highlands. Stevens et al (1985) dated the start of this alluvial type of sedimentation at approximately 23 Ma and believes that it was episodic in nature. Formations of this type identified by Stevens et al (1985) are shown in Figure 25. In addition to these, Clark, D.F. (1984) attributes the Santa Fe Group exposed in the border region of Mexico to this type of deposition. The Miller Bros., #1 Thomas 139 well of Presidio County, encountered over 800 feet of coarse grained Tertiary clastics, that Pearson (1985) attributed to this type of uplift and erosion. Another example, the Hueco Bolson, northwest of the study area, is reported to be filled with over 4,500 feet of unconsolidated sediments (Pol,

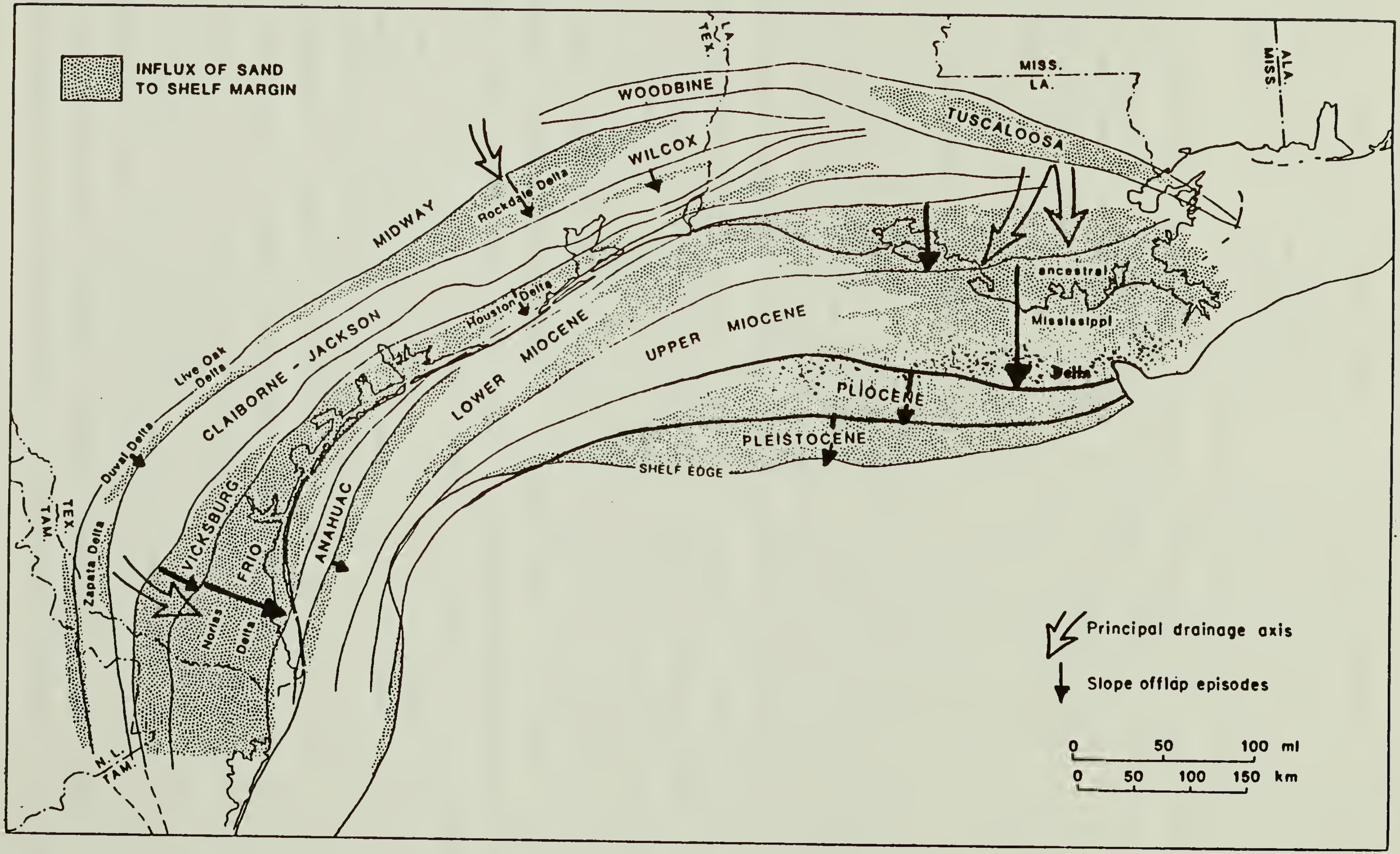


Figure 22. Major sand influxes into the Gulf Coast Basin. The three upper Wilcox deltas in South Texas represent the final stages of Laramide infilling of the Rio Grande Embayment. The major Vicksburg-Frio depocenter in the Rio Grande Embayment coincides with Basin and Range tectonic activity. (from Jackson et al, 1984, Winker, 1981, 1982)

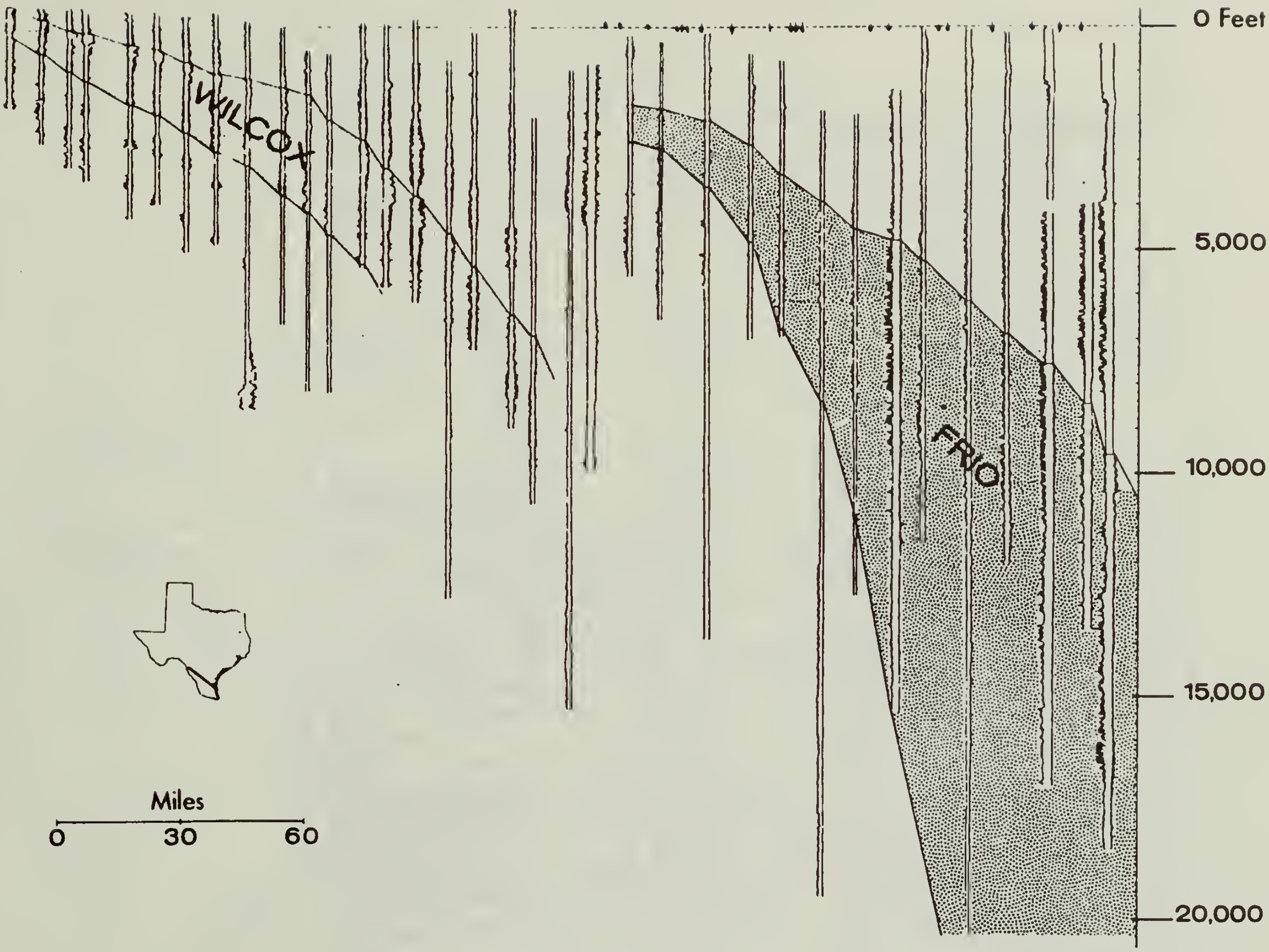


Figure 23. Regional cross-section through the Rio Grande Embayment, illustrating the thick sequence of Wilcox (lower Eocene) and Frio (Oligocene) clastic sediments that accumulated in response to Laramide and Basin & Range tectonics respectively. (from Bebout et al, 1980)

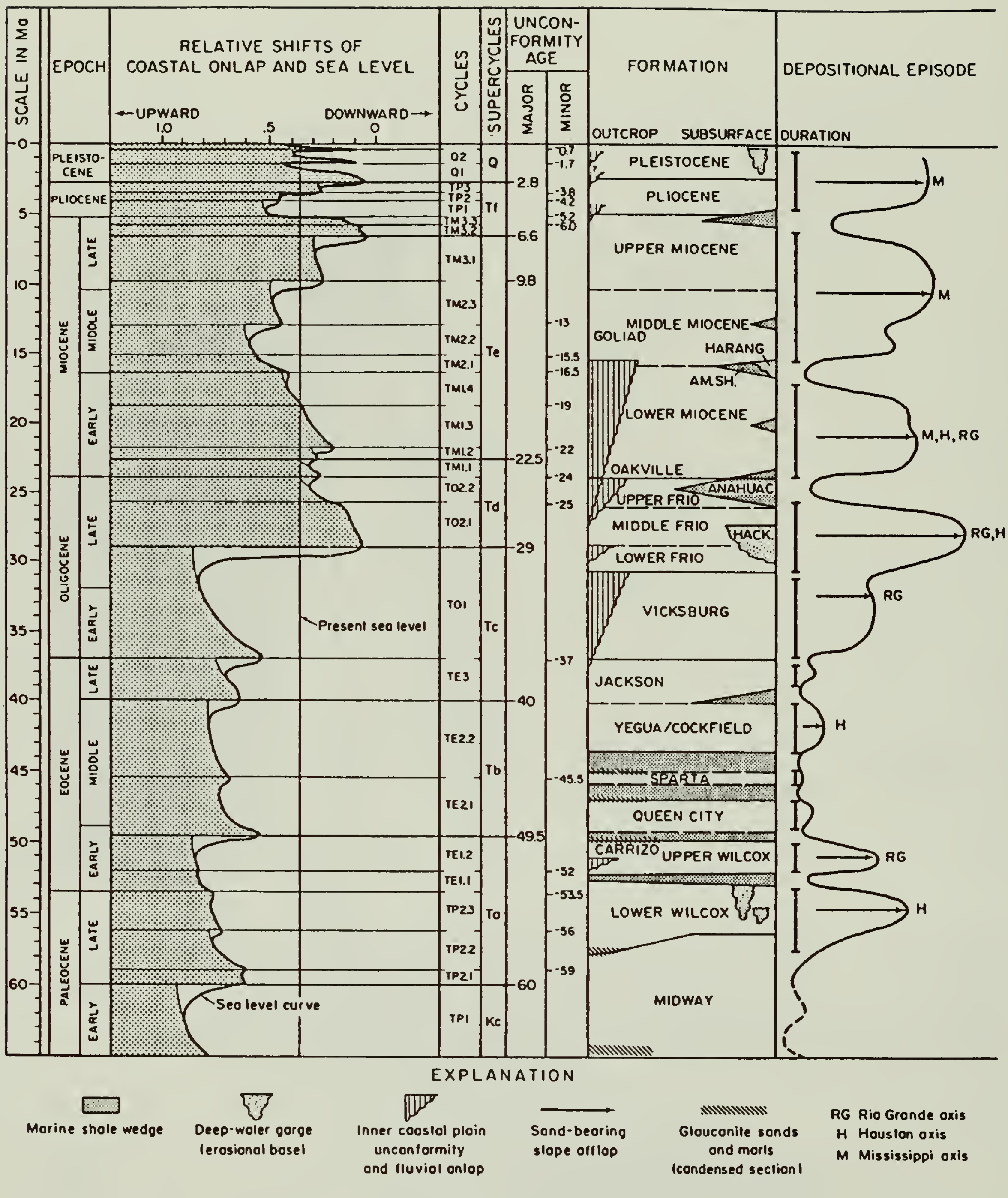


Figure 24. Gulf Coast Cenozoic depositional sequence, showing major depocenters. Note the pulses of clastic sedimentation in the Rio Grande Embayment, coinciding with the close of Laramide tectonics (early Eocene) and Basin & Range tectonics (Oligocene). (from Jackson et al, 1984)

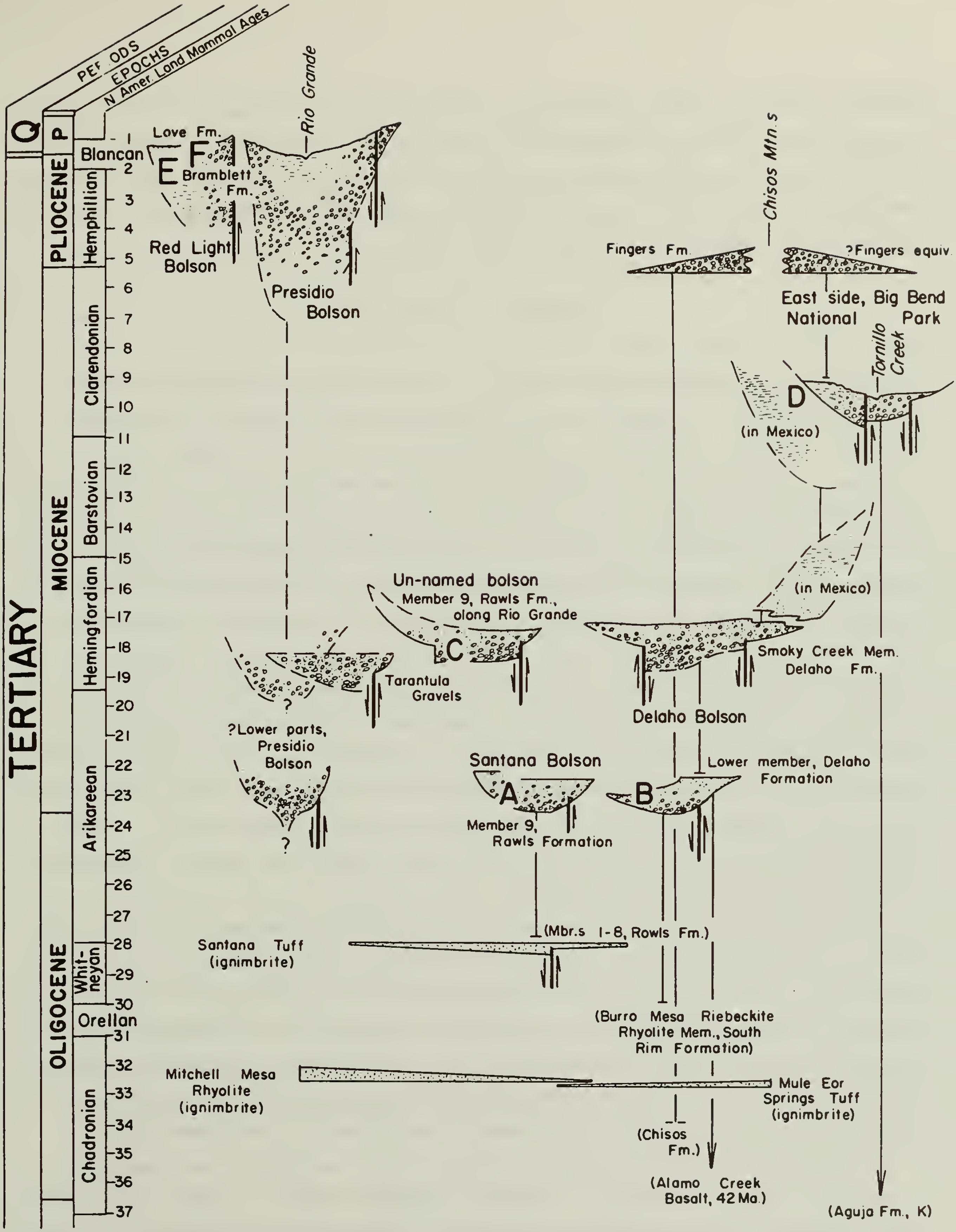


Figure 25. Table shows sequence of late Cenozoic syntectonic intermontane basin fill deposits described and dated by Stevens and Stevens (1985). Note the episodic nature of common basin fills. A-F represent local fossil vertebrate fauna. (from Stevens and Stevens, 1985)

1985). Belcher (1975) reports that it is likely tht these basins actually captured the drainage systems for periods of time until sufficient basin filling had taken place to allow spillover and once again permit through flowing drainage. This type of history may account for the episodic record of basinal fill described by Stevens et al (1985).

SUMMARY & CONCLUSIONS

The Rio Grande-Trans Pecos region of West Texas and northeastern Mexico is an area which has undergone considerable amounts of syntectonic deposition, in response to the periods of orogenic activity that have taken place in the region. The region is an integral part of the overall tectonic history of the North American craton. This regional history is the driving force behind the localized tectonics of the area, and thus the synorogenic sedimentation of the region. For instance, the compressional event of the Precambrian Grenville Orogeny (1,380 Ma to 1,000 Ma) followed by late Precambrian rifting (850 Ma) established northwest-southeast trending lines of crustal weakness in the region, including the Mojave-Sonora megashear. These crustal discontinuities subsequently played a key role in the tectonic history of the area of study, in that they were continually reactivated to compensate for the tectonic stresses applied to the region, either locally or from distant part of the North American craton. Movements along these zones controlled the type of deformation that wold take place and therefore the type of syntectonic sedimentation that would result from a tectonic event.

The earlies syntectonic sedimentation of the Rio Grande-Trans Pecos region was the Precambrian Carrizo Mountain Group, resulting from an early rifting event at 1,500 Ma. The later compressional and thrusting event of the Grenville Orogeny (1,380 Ma to 1,000 Ma) resulted in the syntectonic alluvial deposition of the Hazel Conglomerate. The Precambrian closed with strike-slip movement along wrench faults transecting the region and uplift resulting in an erosional period and the alluvial deposition of the VAn Horn Sandstone.

During the Paleozoic, the majority of synorogenic sedimentation is associated with the Ouachita compressional event (Mississippian to Permian). The earliest of these deposits include the thick sequence of flysch and molasse sediments which accumulated in the foredeep basin (Marfa and Val Verde) which developed north of the northward spreading fold and thrust belt. These

deposits include the Tesnus, Haymond, and Gaptank Formations. As compression continued, deformation and erosion of older Ouachita syntectonic deposits as well as older Paleozoic and Precambrian rocks also continued. Detrital material continued to be deposited as deformation proceeded. The Permian Powwow conglomerate is an example of this later phase of syntectonic sedimentation. The Powwow was deposited as coalescing alluvial fans on a deeply eroded surface.

The early Mesozoic in the Rio Grande-Trans pecos region was characterized by "Transtensional" deformation, resulting in the formation of the Chihuahua Trough and the Rio Grande Embayment. The Chihuahua Trough being the most proximal basin to the Rio Grande-Trans Pecos region was the first of the two basins to receive syntectonic sediments. The earliest of these deposits were of a syntectonic origin. Along the perimeters of the basin conglomerateic sediments accumulated in aluvial fans. Examples of this type of sedimentation would be the Jurassic La Cassita Formation, the basal Cretaceous Glance Conglomerate, the Yucca Formation, and a conglomerate identified southwest of Big Bend.

From late Cretaceous to middle Cenozoic time, the area of study was influenced by the uplift, folding, and thrusting activity of the Laramide Orogeny. The Ojinaga Basin formed in front of the advancing orogenic belt and received a late Cretaceous alluvial-deltaic sequence. Also in late Cretaceous time, the precursors of the present day Pecos, Rio Grande, and Rio Conchos drainage systems developed. the thick sequence of Tertiary clastic sediments present in the Rio Grande Embayment of the Gulf coastal plain are evidence that at this time the embayment became a primary receiving area for sediments of the San Miguel, Olmos, and Escondido Formations into the Maverick and Sabinas basins on the north end of the Rio Grande Embayment. This pulse of syntectonic sedimentation in the embayment continued to early Eocene, culminating with upper Wilcox deltaic sedimentation farther south in the embayment. Within the Rio Grande-Trans Pecos region, compressionally formed receiving basins on the flanks of uplifted areas were also the sites of synorogenic alluvial sedimentation associated with Laramide deformation. The basal Tertiary Jeff Conglomerate is an example of such a deposit.

Basin and Range extensional tectonics replaced the compressional regime of the Laramide orogeny in middle Cenozoic time and persists to the present. The thick accumulation of Oligocene Vicksburg and Frio sediments within the Rio

Grande Embayment resulted from this deformational episode. Also during this time, the asymmetric intermontane basins formed by extensional block faulting became primary receiving areas for syntectonic deposits eroded from horst block highlands. These basins commonly received several thousand feet of unconsolidated clastic sediments. The nature of accumulation in these basins was typically episodic. Drainage systems transecting the region was commonly captured by intermontane basins until sufficient basin filling had taken to permit through flowing drainage and the transport of tectonically derived clastics to the Rio Grande Embayment.

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WITHIN A BEND OF THE RIVER

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The Big Bend is located in the great northward arc of the Rio Grande River some 250 miles down river from El Paso. Dotted by a few mountains the Big Bend is largely composed of the desert lowlands of the Chihuahuan Desert. Man has endured the natural harshness of the area time and again for the last 12,000 years. Indians, Spaniards, ranchers, miners and outlaws, to name a few, all inhabited the Big Bend at one time. Most are gone, but a few remain to tell the story of one of our most unique natural areas.

The earliest substantiable evidence of man's existence in the Big Bend area dates back to about twelve thousand years ago in the late Pleistocene. These early inhabitants were nomadic hunters that depended primarily upon the taking of large game for their survival. After a few thousand years, the climate changed with the recession of glaciers during the end of the last glaciation period. This resulted in a long drought which either caused extinction, or at least expulsion, of those large game animals from the area. With his primary food supply diminishing, early man soon disappeared from the Big Bend (Casey, 1972). For the next two thousand years, Big Bend seems to have remained virtually uninhabited by man. However, around six thousand years ago man began to re-enter, but with a quite different style of life than his predecessors. Through his use of crude stone tools and a basic understanding of agriculture, Archaic man was able to lead a much more sedentary life and inhabited the fertile stretches along rivers and streams. He established actual homesites and constructed permanent residences. By A.D. 900-1400 man in the Big Bend had acquired the use of bows and arrows which greatly increased his ability to harvest game (Casey, 1972). As he became more settled, man began developing socially into small groups and then into tribes. By the time the Spanish arrived, the Indians in Big Bend had a structured tribal government and some form of religion.

In the early 1500's Spanish expeditions crossed the Atlantic to explore the New World and found much wealth among the natives they first encountered.

The discovery of the Aztec empire and its great wealth by Hernando Cortez in 1521 only encouraged more expeditions. In 1528 Panfilo de Narvaez left from Spain to explore from the Rio de Las Palmas (the Rio Grande River) to the peninsula of Florida. However, for some unknown reason, they first landed on the coast of Florida and explored west. Separated from their ships and the main body of the expedition, some 200 men attempted in vain to reach New Spain -- present day Mexico -- by crossing the Gulf of Mexico in small, crude boats. Most of the crafts were lost at sea but a few washed up on Galveston Island under the command of Alvar Nunez Cabeza de Vaca. After six or seven years as a captive and then as an honored medicine man of the Karankaws indians, Cabeza de Vaca escaped with three other men and headed for New Spain -- or so they believed. New Spain was southwest, and they headed northwest. His wandering took him across the Rio Grande a number of times and most probably through the Big Bend area (Casey, 1972). Shortly thereafter, they encountered a Spanish slave-hunting party and returned to Mexico City. Once again the Spanish, upon hearing of civilization to the north, anticipated much wealth and sent numerous expeditions in search of it.

The Coronado expedition (1524-1543), the Rodriquiz-Chamuscado missionary expedition (1581-1582), and the Espejo expedition (1582-1583), to name a few, were beginning to convince the Spanish that even if there was great amounts of gold, which they had not yet found, the price was a little too high. The desert terrain was, and is, quite unforgiving to anyone not familiar with its hazardous and unpredictable ways. Also, the peaceful Jumanos indians they first encountered were now being raided on a regular basis by the relentless and hostile Mescalero Apache, the Comanche and the Kiowa (Tyler, 1975). Spanish influence continued in the Big Bend for the next 200-250 years. San Vincente and San Carlos missions were still attempting to convert and protect the Jumanos from the ever fierce Apache and Comanche raids. Time and again Spanish forces were sent to Big Bend to repel the hostile indians but to no avail. In the early 1800's the Spanish missions of San Vicente and San Carlos were closed (Tyler, 1975). The indians were not begging to be converted and they obviously did not possess any great amounts of gold. Mexico gained here independence from Spain and Texas hers from Mexico. In 1848 the Treaty of Guadalupe Hidalgo was signed and Texas became part of the United States, but the Big Bend was still ruled by the indians.

In 1847 Ben Leaton, John W. Spencer, and John D. Burgess established a mercantile business in Presidio in the northern Big Bend. This new outpost was situated along the Chihuahua Trail, which was intended to induce trade between New Orleans and Chihuahua, Mexico. Besides being the first American settlement in Big Bend, Leaton's store at Presidio was the only inhabited outpost since the closing of the old Spanish missions of San Vicente and San Carlos years before (Casey, 1972). Numerous expeditions soon left from San Antonio, Houston, and Corpus Christi for the Big Bend. Although every expedition found the terrain rough and the passage quite difficult, they were all driven by the hope of striking it rich on gold or silver, or the rather profitable trade between Texas and the lands to the west. These newcomers to the Big Bend were easy prey to the ever present Apaches and Comanches. Forced from their native more fertile lands to the north, the indians found that survival was attained much easier by preying on wagon trains and the few small villages of other peaceful indians and settlers than to attempt growing food themselves on the relatively infertile desert terrain. The pillaging became so bad, in fact, that the Mexican governments of Chihuahua and Durango offered as much as $200, and sometimes more, for the scalps of "unfriendly" indians (Tyler, 1975). This may have served some purpose, but realistically it only brought in more undesirable types to the Big Bend. Infamous scalp hunters such as James "Santiago" Kirken were feared by all, friendly or unfriendly, Indian, Mexican or Anglo. Besides, what official could tell whether the dried scalp was from an "unfriendly" indian or anyone else -- and what scalp hunter really cared at $200 a scalp?

Obviously, if a permanent settlement was to exist here, something had to be done. In 1848 Lt. Col. Joseph E. Johnston, Chief Topographical Engineer of Texas, was assigned to explore the Rio Grande and to search for an army post site. Hopes existed that the Rio Grande would be navigable and thus provide a much more efficient and economical means of overland transportation. Although deservedly accredited with the construction of the first accurate map of Big Bend, Johnston only retrieved a minimum of information about the land itself. In 1852, the first successful expedition, the Green-Chandler expedition, surveyed from Presidio down the Rio Grande to Reagan Canyon. On this International Boundary Commission survey, important information was gathered about the Bofecillos and Chisos Mountains and Santa Elena, Mariscal, Boquillos, Maravillas and Reagan Canyons (Tyler, 1975). A few other surveys were made of

the Rio Grande River but time and again the same conclusion emerged -- the Rio Grande was unnavigable to trade vessels and the indian raids were still a major problem. Thus, the only way to enhance transportation was along a better road and with this improvement came the need for more protection. The need for more protection was met in 1854 with the establishment of Fort Davis. For nearly thirty years the cavalreis stationed at Fort Davis battled with the indians. Finally, in 1881, the last of the great chiefs of the Muscalero Apache, Victorio, was killed in a battle with Mexican troops at Tres Castillas in northern Mexico. Their spirit broken, the last of these marauding renegades accepted defeat and were moved to reservations in other areas (Tyler, 1975).

During their stay at Fort Davis, the U.S. Army conducted several experiments, one of which is quite unusual and worthy of mentioning. Wanting to increase their ability to move over rugged terrain and carry heavy loads, the use of camels in the southwest was suggested. The rugged Big Bend area was the ideal place. So, in 1859 the camels arrived at Fort David from San Antonio. Leaving shortly on their experimental journey, the camel caravan crossed through Dog Canyon and much of the present day national park. The camels performed their task most adequately due to their ability to store enormous amounts of water and to withstand the harsh elements of the desert and mountain terrain. Unrest between the north and the south resulted in the removal of the Union forces from Fort Davis. Although successful in their experiment, the camels were quickly replaced by the railroads after the Civil War.

In the early 1880's the railroads arrived in Big Bend and towns sprang up at rail stations soon to be known as the towns of Alpine and Marfa. With the indians subdued and the transportation problem greatly reduced, the population of the Big Bend began to grow. Businesses were established as more people arrived and the towns began to grown. Large ranches, such as the G4, the Spencer and the Faver ranches covered vast areas and produced multidues of cattle, sheep, and goats. Of those original ranches a few have survived and still operate today in the Big Bend.

Soon after, mining started in the Big Bend near the Faver Ranch in the Chinati Mountains. Recognized more commonly as the Shafter Mine, this mine produced in excess of $20,000,000 in silver from its more than 100 miles of shafts (Tyler 1975). Coal and lithographic limestone were discovered in the early 1900's but neither was ever significantly mined.

In 1901, however, significant amounts of cinnibar were discovered near the small town of Terlingua. The quicksilver rush was on and many mining companies staked their claims and began operations. Initially mined by the Marfa and Mariposa Mining Company, the Terlingua mining district saw no companies more productive than the Chisos Mining Company. Organized by Howard E. Perry of Chicago, the Chisos Mining Company was the dominant mine in the area and remained productive until the close of WWI when the price of mercury plummeted. Today, the remains of the once very active mine stand out against the hills near Terlingua. The mine shafts are still there, some with structures above them, others merely deep holes in the ground. Ruins of the post office, jail, general store and assorted miner's cabins dot the hillside around the present day Terlingua Ghost Town. Perry's house, still dominating the hillside and the cemetery bordered by a fence held up mostly with stray tumbleweeds, reminds us of both the plush and the hard times endured during the boom times of Terlingua.

Wax makers entered the area in 1911. With the abundant candelilla plant as its source, wax was easily attainable. The candelilla plant as its source, wax was easily attainable. The candelilla, a small shrub with branches 14-18 inches long radiating from its base, was heated in diluted sulfuric acid, and as the wax separated from the plan it would float to the top. The wax was then skimmed off and poured into barrels. Today, there are still a few wax plants in operation, but the need for great amounts of this wax has subsided. Another short-lived livelihood in the Big Bend in the early 1900's was fur trading. Bobcat, coyote, fox and beaver pelts were among the most common. These pelts were traded at various trading posts throughout the area for staples but none more fairly than at Johnson's Trading Post (Tyler, 1975) located in what is today the southern part of Big Bend National Park.

The ranches, mines, and candelilla through livestock, ores and wax brought an effective wealth to the Big Bend -- effective enough to maintain a few towns, establish some banks and, yes, lure bank robbers, bandits, and rustlers into the area. Fairly peaceful since the subduing of the indians in 1882, these outlaws brought quite an unrest to the Big Bend. Spurred on by the removal of troops in 1913, lawlessness continued to increase and the raids and robberies became more frequent and severe. Pancho Villa himself undoubtedly made his presence known in the Big Bend but is surely accredited with more raids than even he could have possibly led. On the night of May 5, 1916, two

of the worst raids in Big Bend history occurred. Seventy to eightly bandits crossed the Rio Grande near the old San Vincente mission and raided the villages of Glen Springs and Boquillas. At Glen Springs, the town was looted by a large portion of the original band. During the raid a number of citizens were killed, including a 7-year-old boy, Tommy Compton. His father had taken his sister to a nearby home thinking she would be safer there but did not return to his store before the bandits murdered Tommy. His deaf-mute brother, incidentally, wandered around the village unharmed during the raid (Tyler, 1975). Everything that could be packed on a horse was taken, except for the sauerkraut. Evidently, the bandits thought it was spoiled and left it. Shortly afterwards, the remainder of the bank arrived at Jessee Deemer's store in Boquillas. Deemer and his Negro clerk, Monroe Payne, avoided a fight but were forced to load the bandits' horses with all the supplies they could carry and were taken prisoners. These raids, in addition to Pancho Villa's raid on Columbus, New Mexico just two months before, enraged the citizenry of the entire nation, and they demanded action. Troops A & B of the 8th Cavalry under Major George T. Longhorne were assigned the task of rescuing the prisoners and punishing the bandits. Though a cavalry with horses, it should be noted that Maj. Longhorne crossed the country in his Cadillac and was accompanied by newspapermen and a film crew to record this "great" event (Tyler, 1975). Fifteen days and 550 miles later, Longhorne completed his mission. He rescued the two prisoners, caught five bandits, wounded or killed a few more, and retrieved most of the supplies taken from the two stores. Other raids occurred, such as the Nevill Ranch Raid in 1918 by the infamous Mexican bandit Chico Cano, but through the persistence of the cavalry and other law enforcement agencies the violence quickly died. Most settlers returned to their farms, ranches and mines, and the Big Bend became relatively peaceful again (Tyler, 1975).

During the following years more and more people came to the Big Bend and experienced its beauty, ruggedness and individuality. In 1933 Gov. Miriam A. ("Ma") Ferguson signed a bill which established Texas Canyons State Park. Later that year, in October, Gov. Ferguson signed another bill which added 150,000 acres to the existing park. E.E. Townsend, an early inhabitant to the Big Bend, was still not satisfied. Working in the Big Bend as a Texas Ranger, a U.S. customs inspector, and a number of other professions, Townsend had always envisioned the area as a national park. He continued his lobbying and

persuading until finally, in 1944, Big Bend National Park became a reality.

The State of Texas deeded 707,894 acres in the Big Bend to the federal government in February 1944 for the establishment of a national park. Twenty years would pass before the park facilities would be completed, but today the Big Bend National Park is a reality. The Big Bend area, devoid of most of its outlaws and lawlessness, is once again quiet and peaceful. Now mostly legends survive. However, as some of them tell, there may be ghosts lurking behind the apparent serenity of the Big Bend.

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Review of Exploration and Hydrocarbon Potential in Southern Trans-Pecos Texas

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Introduction, Purpose and Methods of Investigation

Philip B. King said in the early 1900's, that "West Texas was an area geologists were sent to, when no one else knew what to do with them". Thought to be a wasteland, West Texas was considered a Siberia for geologists. Now the Permian Basin is a prolific hydrocarbon province.

At one time, there seemed to be no limit or geological boundry in West Texas where a wildcatter could not make a well. Help from geologically uninhibited drillers proved the Permian Basin to be in reality, two rich basins separated by an oil filled platform (see Figure 1). Production was established in all directions until drillers came upon far West Texas, known as the Trans-Pecos region. Although shallow and deep production is established in the eastern margin of the Trans-Pecos, there does appear to be a hydrocarbon limit, over which past exploration efforts have failed.

The purpose of this paper is the briefly review past exploration efforts, make suggestions as to their reasons for failure and show that potential to find oil and gas exists today in southern Trans-Pecos Texas. Only Jeff Davis, Presidio and Brewster Counties will be reviewed (see Figure 2).

Information supporting exploration efforts and potential came from field research scientists, exploration geologists and personal communication. Petroleum Information, Inc., Tobin Research Inc., and

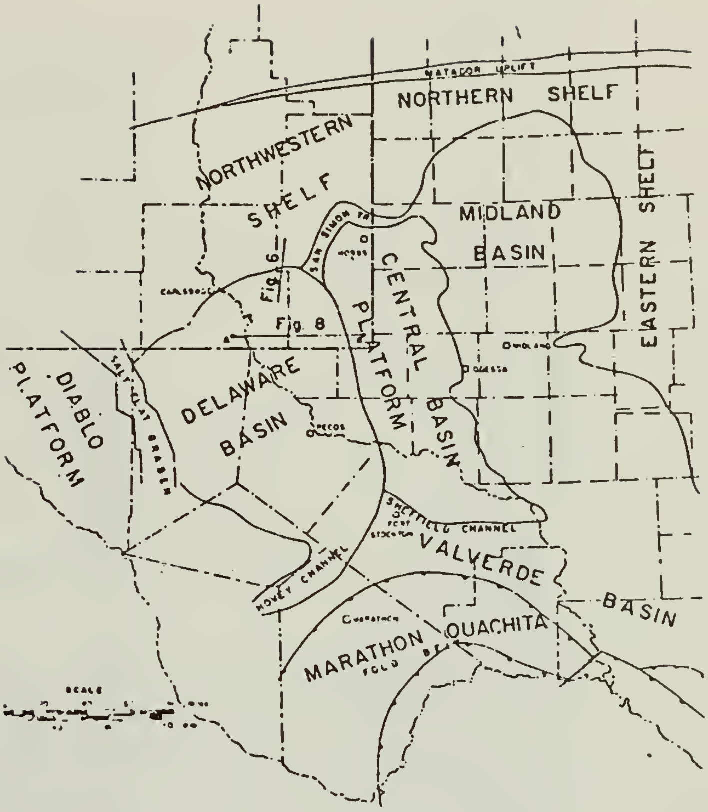


Fig. 1 Location of Permian Basin in West Texas (After Hills 1985)

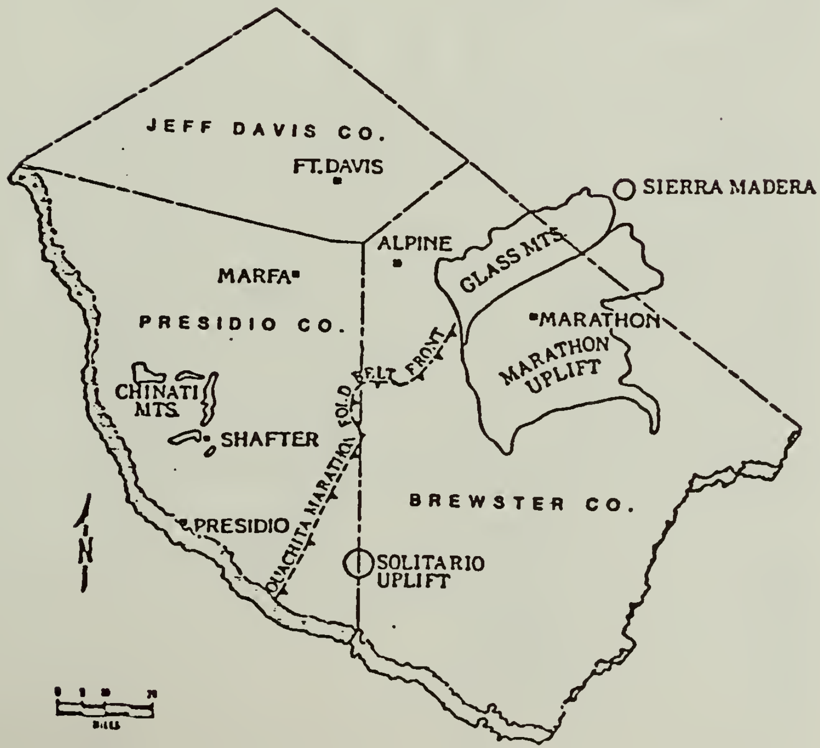
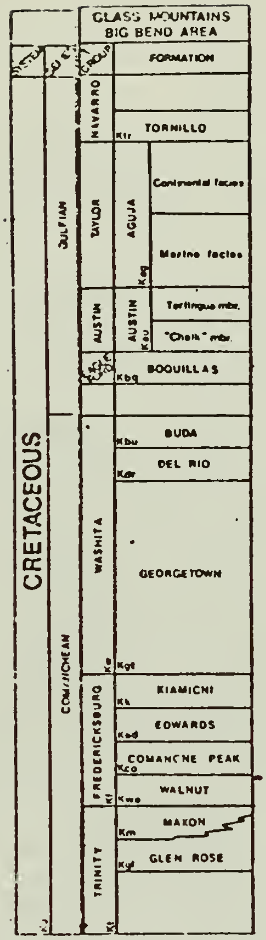


Fig. 2
Diagram of Jeff Davis, Presidio and Brewster Co. (After Pearson, 1981)



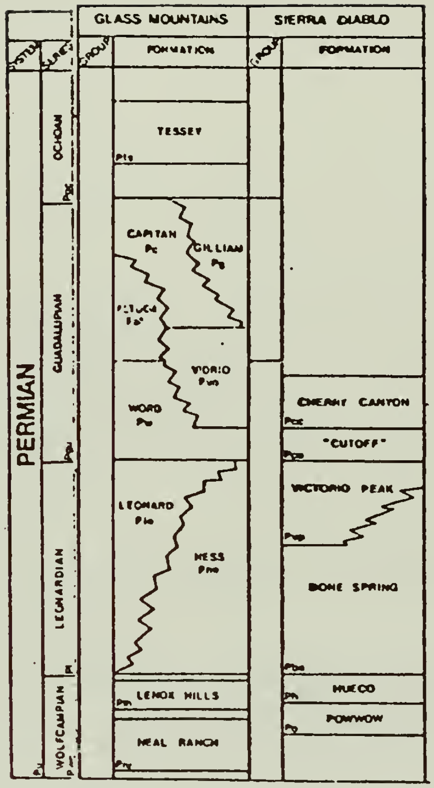
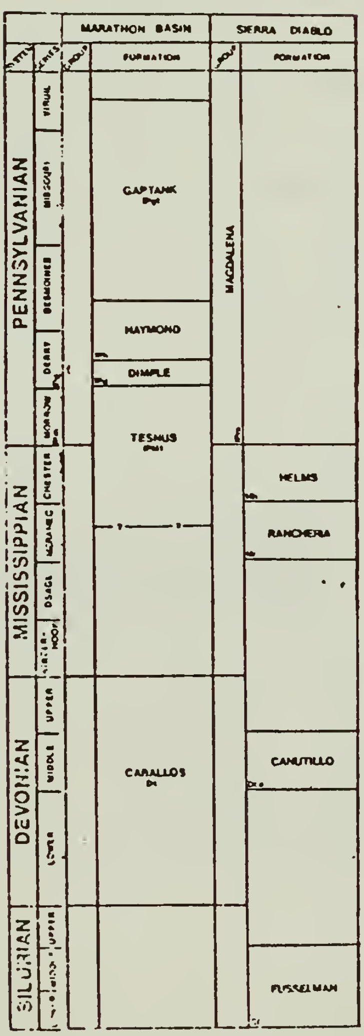
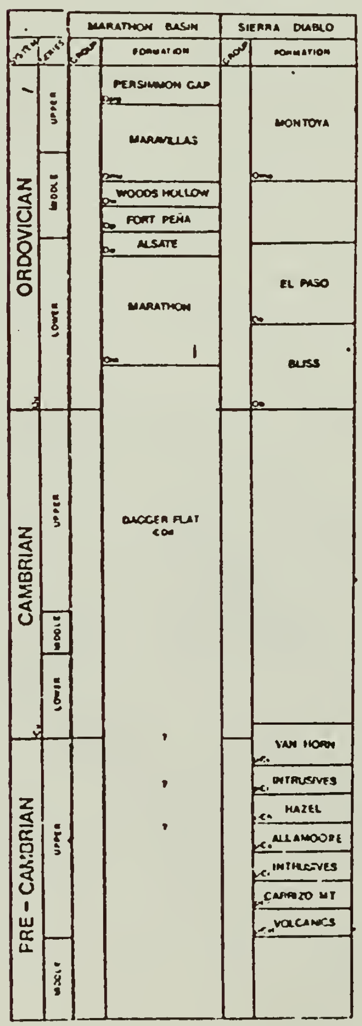


Fig. 3

Stratigraphic tables from WTGS Fieldguide and Petroleum Frontiers





TIME (Ma)	SYSTEM	FORMATION
	Permian	Leonard Wolfcamp
280	Pennsylvanian	Cisco Canyon Strawn Atoka
310	Mississippian	Chester Pre-Chester Woodford
345	Devonian	"Devonian Limestone"
405	Silurian	"Upper Silurian Shale" Fusselman
425	Ordovician	Montoya Simpson Ellenburger
500	Upper Cambrian	Bliss
600	Precambrian	

Geomap Inc., provided data to summerize past exploration. I am indebted to all these people and companies.

Exploration and Potential -

Underlying Tertiary volcanics and volcaniclastics is a thick section (composite = +20,000 ft.) of marine sediments ranging from Cambrian sandstone to Cretaceous limestone (see Figure 3). This section has been drilled and tested without commercial success. Target formations have been the Ordovician Ellenburger limestone (dolomite), Simpson and Montoya groups, Silurian Fusselman carbonates, Devonian and Pennsylvanian carbonates and sands and Permian limestones and sands. Targets in the Mesozoic have been Commanchean and Gulfian Cretaceous limestones and sands.

Wells drilled to test lower Paleozoic strata have found the formations to contain freshwater. The Continental Oil Company 1# McCutcheon, was drilled to 9563 feet along the eastern edge of the Serria Diablo Platform (see Figure 4) (Pearson, 1985) testing Star Mountain Anticline in eastern Jeff Davis County. The well penetrated 300 feet of Ellenburger (top = 9245') and oil shows in samples of the interval 9362-79 feet were recovered. A drill stem test was run over the interval and recovered 240 feet of mud and 7200 feet of fresh water. Diagram "A" illustrates that 70% of the wells drilled in Jeff Davis County were drilled below 5000 feet and were looking for lower Paleozoic rocks. Of all wells drilled in Jeff Davis County, 55% reported finding fresh water. The same is true in Brewster County but a significant number of wells (57%, see diagram "B"), did not reach below 5000 feet as lower Paleozoic rocks generally lie deeper in Brewster County. Of the wells drilled in Brewster County, 29% found fresh water. In Presidio County, 80% of the wells drilled tested below 5000 feet and although lower Paleozoic rock usually lay deep, 23% of the wells found fresh water (diagram "C"). Actually the fresh water statistic is probably much higher as companies sometimes leave their findings unreported.

Major changes in facies allowing for development of permeability and porosity barriers did not evolve in the shelf carbonates of the

lower Paleozoic (Feldman, personal commun.). Whatever hydrocarbons that were contained in these rocks were apparently flushed to the surface or into the Delaware basin by meteoric waters entering at the outcrop or diluted beyond commercial value. Pearson (1985), Luff (1981), Dejong et al (1985) agree with this conclusion.

Pearson suggests other reasons for lack of significant amounts of hydrocarbons yet to be found. Pearson (1985) observed that thick sequences of shales and evaporites found in the Permian Basin proper are missing in the Trans-Pecos, Texas. Shales act as both source and seal for hydrocarbon entrapment and evaporites have long been known as an effective seals over potential pay zones. Also, shales and evaporites sometimes have a healing effect (Pearson, 1985) over fractured zones and faults. Dejong et al (1985) suggest that faults in the region are not sealing and allow migration of fluids out of the trap.

The effects of repeated deformation are recorded in the rocks of the Trans-Pecos. A northwest structural grain developed during late Precambrian (Muehlberger, 1980) setting the stage for what later became a major basement-arch complex covering Southern Arizona and New Mexico, Western and Northern Texas and Southern Oklahoma (see Figure 5). Tectonic studies of the region conclude that deformations occurred in the Precambrian (Muehlberger, 1980), the Late Paleozoic Ouachita-Marathon orogeny (Dickerson, 1985), Late Jurassic-Early Tertiary (Longoria, 1985; Moustafa, 1983) and Late Tertiary-Quaternary Basin and Range Deformation and associated vulcanism (Stevens and Stevens, 1985). Many large structural traps that were formed in Cambrian thru Permian, became victim to Late Pennsylvanian thru Permian deformation. Subsequently traps formed in the Marathon Orogeny suffered the effects of (?) Laramide and Basin and Range deformation (Dejong, 1985). Pearson (personal commun.) considers many of the horsts to be "scalped" of target formation and grabens now look attractive for exploration.

Companies are now trying to extend shallow Marathon overthrust plays into northeastern Brewster County (Fallon, personal commun.). Oil and gas production is established in Pinion (Tenneco) and Thistle (Shell) Fields in Pecos County and McKay Field (Sun Exploration) in Terrell County, (see Figure 6). McKay Field produces oil and gas

Fig. 4
Location of Continental Oil 1# McCutcheon (Modified from Petroleum Froniters)

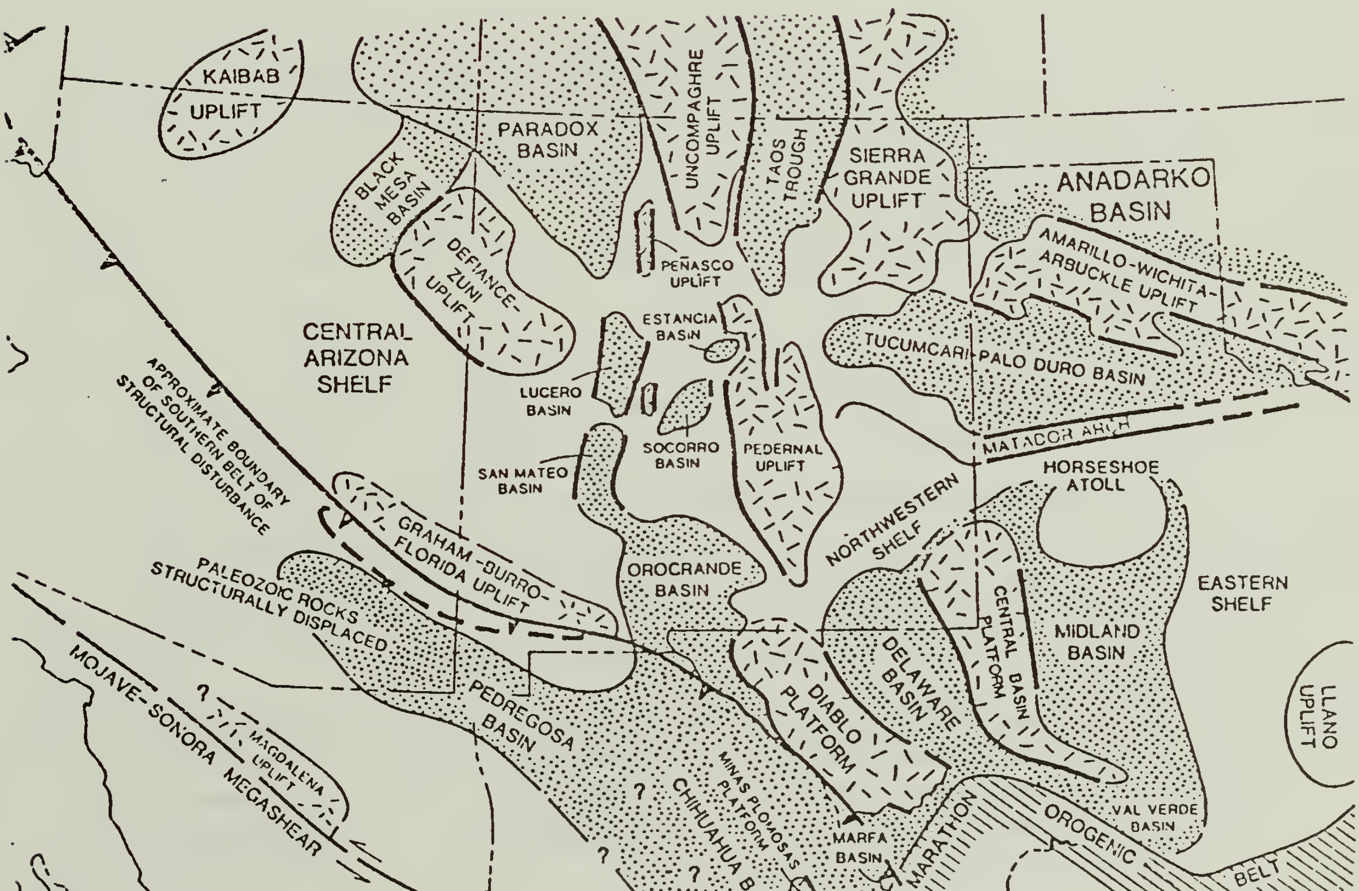


Fig. 5 Illustration of basement-arch complex in southwest U.S. The complex developed in Permo-Penn time. (After Ross and Ross 1985)

Fig. 6 Diagram showing location of Pinion, Thistle and McKay Field (After Petroleum Frontiers)

Well Number	Cumulative Oil	Production Gas
No. 1 McKay Creek A	76,000 bbl	911 MMcfg
No. 2 McKay Creek A	Dry hole (east side of field)	
No. 3 McKay Creek A		200 MMcfg
No. 4 McKay Creek A	Currently completing	
No. 1 McKay Creek B	165,000 bbl	675 MMcfg
No. 2 McKay Creek B	97,000 bbl	71 MMcfg
No. 3 McKay Creek B	9,900 bbl	14 MMcfg
No. 4 McKay Creek B	6,500 bbl	88 MMcfg
No. 5 McKay Creek B		800 MMcfg

Fig. 7 Cumulative Oil & Gas Production thru 1985 for McKay Field in Terrell Co. Field was discovered and is operated by Sun Expl. in 1979 (after Petroleum Frontiers 1986)

primarily from fractured Caballos Novaculite above 6500 feet. Discovered in 1979, nine wells have been drilled to date with seven successful completions, one being completed and one dry hole (see Figure 7). Thistle Field, discovered in 1984, produces oil from fractured Caballos Novaculite above 6500 feet. Ten wells have been drilled to date with six successful completions and four dry holes. Pinion Field, discovered in 1982, produces dry gas from Pennsylvanian Dimple limestone above 4000 feet and fractured Caballos Novaculite above 5000 feet.

These recent discoveries are still in the development stage and companies are planning to futher define the play southwest into the Marathon region of Brewster County. Northwest Brewster County is only a few miles from the developing fields and has essential the same geological make up. New techniques (seismic) should help find prospective analogies in Brewster County to those found in Pecos and Terrell Counties.

Moving west into western Brewster and Presidio Counties finds Marfa Basin (see Figure 8). The present day Marfa Basin and its sister, Val Verde Basin to the east, are foredeeps that formed, were destroyed and then reformed under influence of northwest-northeast spreading Marathon thrust sheets (Ammon, 1981) (see Figure 9). Many companies have written off lower Paleozoic potential in the Marfa Basin due to apparent flushing and high thermal maturation (Dejong et al, 1985) (see Figure 10). Permo-Penn and Cretaceous rocks are still prospective as shows have been recovered in samples. Due to low density (about 1 per 250 sq. mile in the Basin, Luff, 1981) shows should be considered promising.

Amerada Hess drilled the #1-191 Bogel south of Marfa about the time of this publication and reports are, that a significant amount of oil was recovered on a drill stem test in a section above lower Paleozoic strata. Tenneco drilled the #1 Arco fee '17' south of Chalk Draw fault to test the theory that flushing may have occurred after movement (rejuvenation) along the fault (Fallon, personal commun.). Ideas and notions like this will likely prove the area's potential (see Figure 11).

Thus far, little has been said about stratigraphic play potential. As in most prospective regions, structural anomalies are drilled first

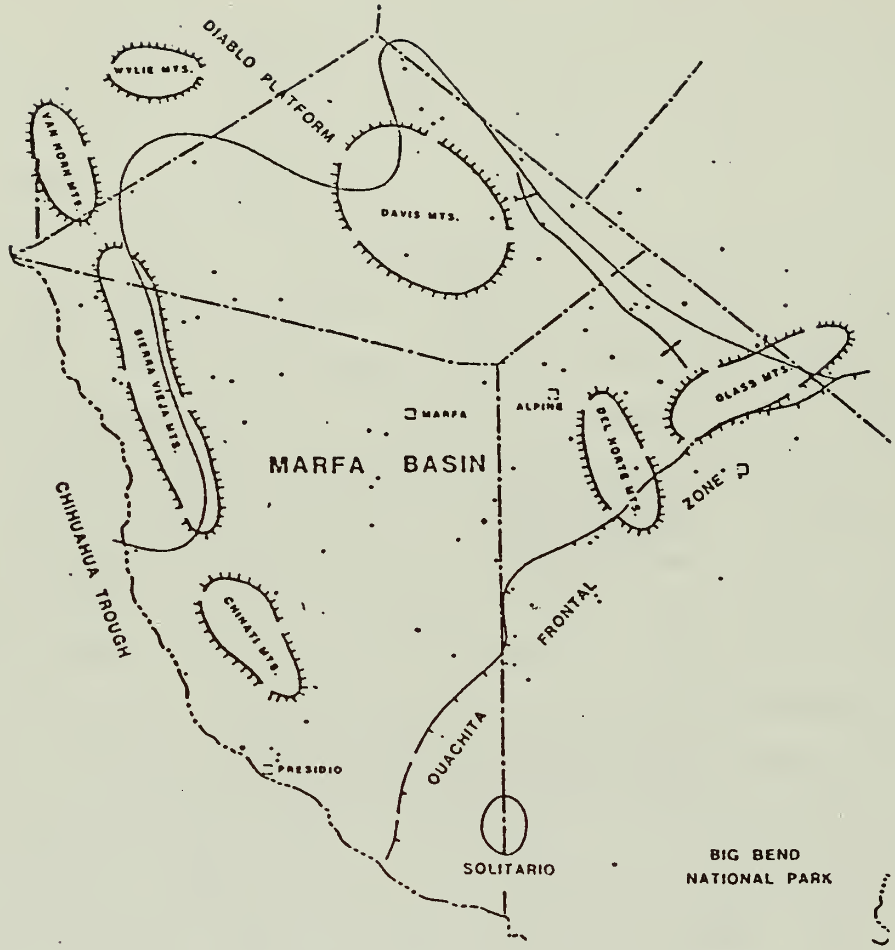


Fig. 8 Illustration showing extent of Marfa Basin in Trans-Pecos, Texas (after Luff 1981)

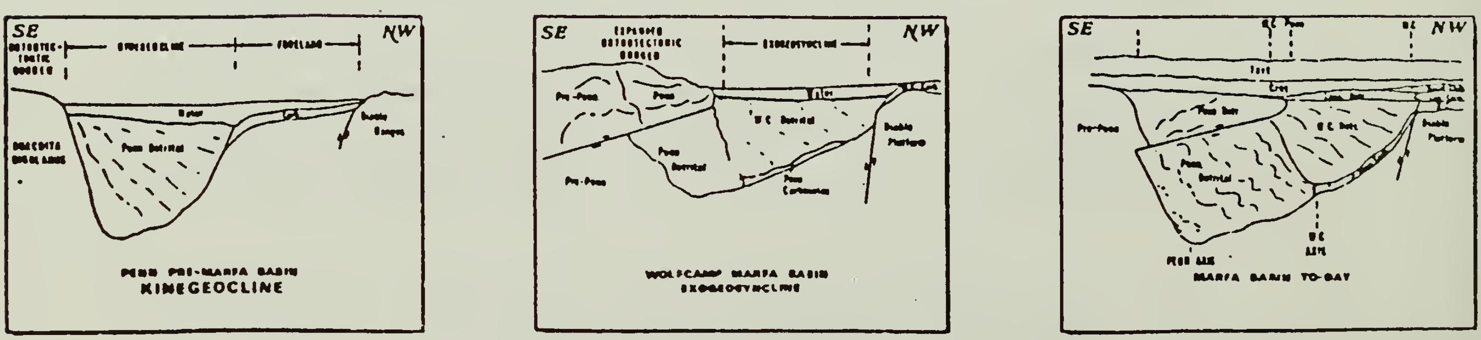


Fig. 9 Diagram by Ammon (1981) illustrating his theory and others of Marfa Basin development

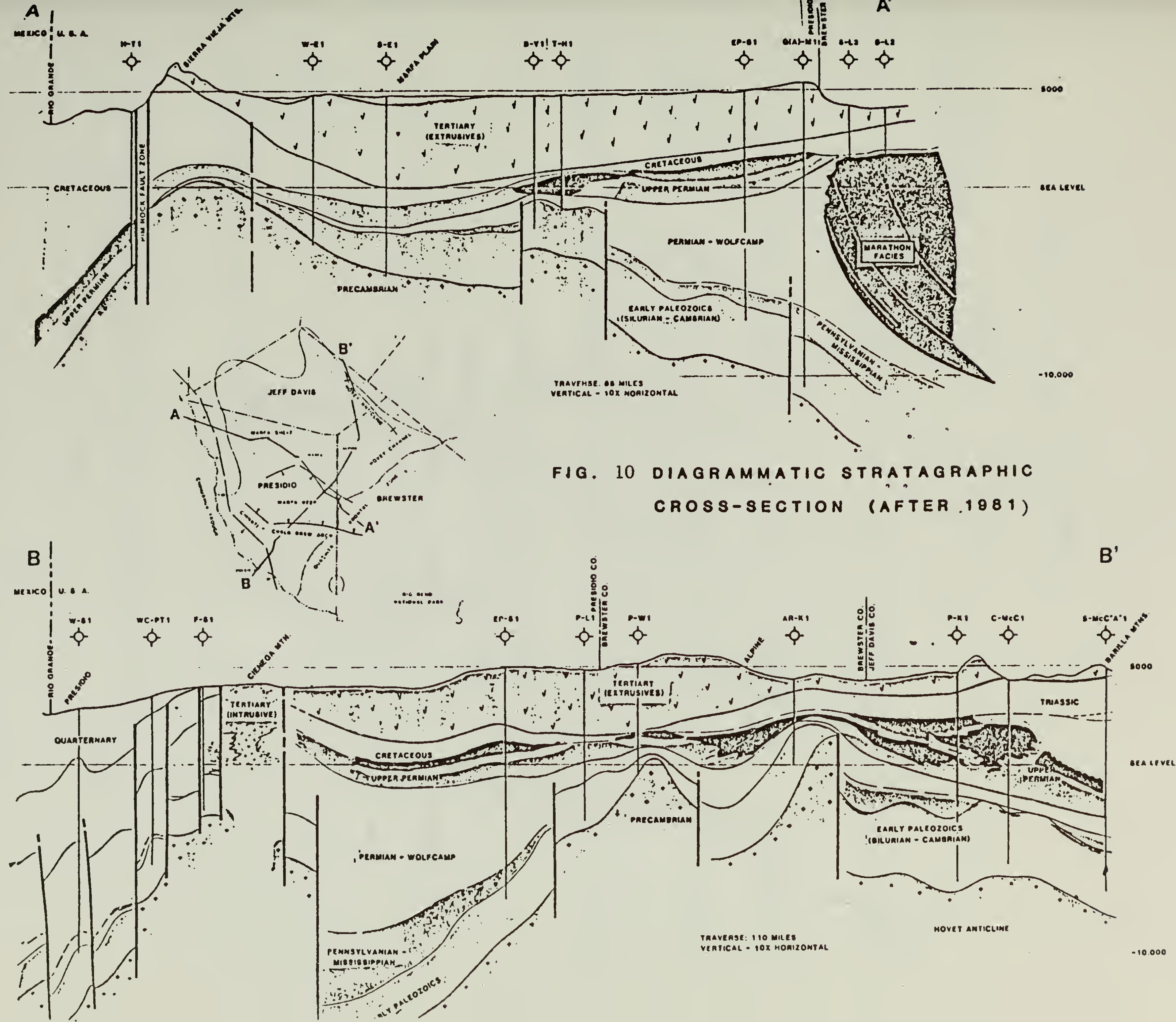


FIG. 10 DIAGRAMMATIC STRATAGRAPHIC CROSS-SECTION (AFTER 1981)

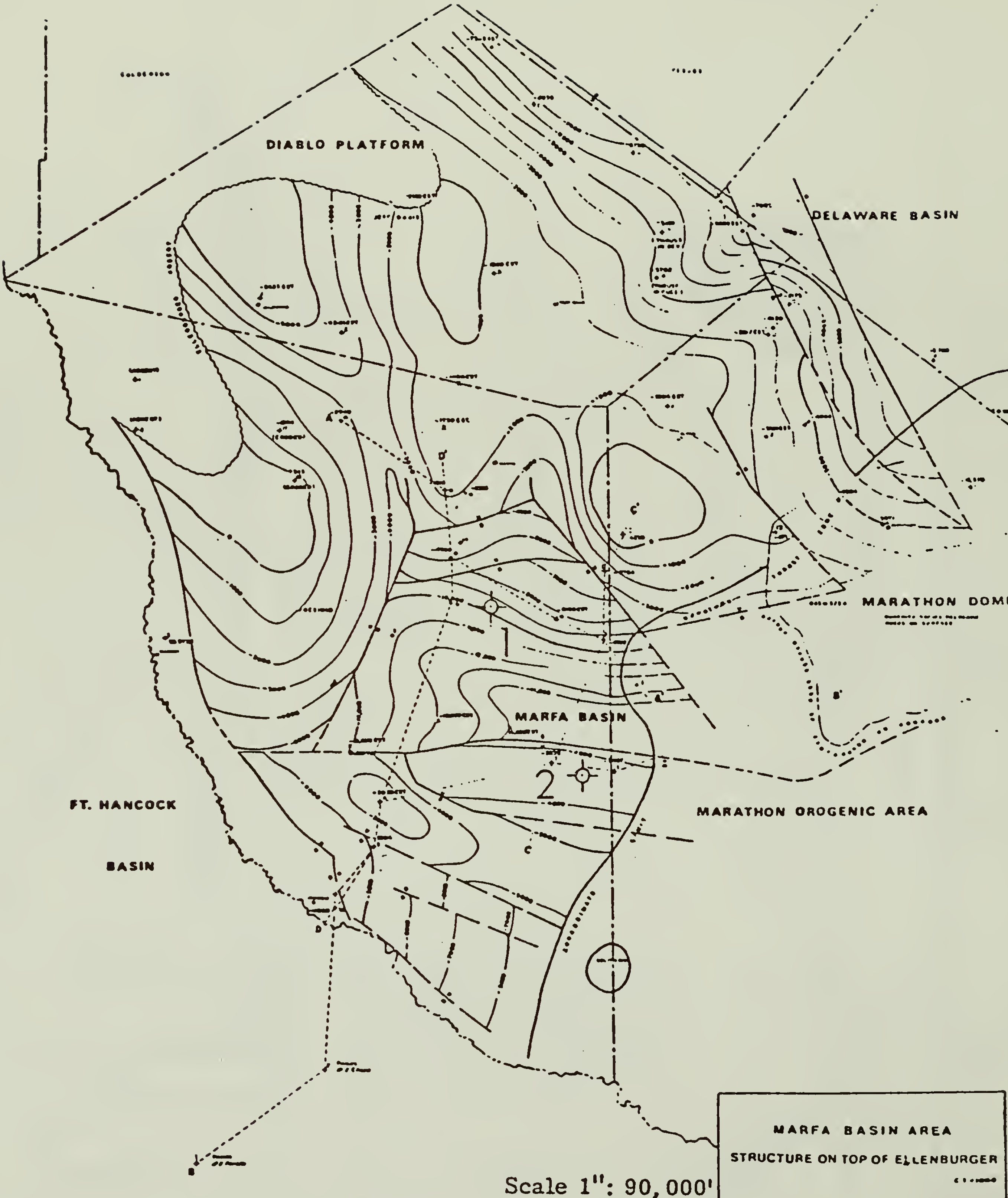


Fig. 11 Map showing approximate location of 1.) Amerada Hess #1-191 Bogel and 2.) Tenneco #1 Arco Fee '17'

DIAGRAM A

DRILLING STATISTICS FOR PRESIDIO COUNTY, TEXAS

NO. OF WELLS DRILLED BY YEAR	1926-40 0 (0)	1941-55 7 (35)	1956-70 9 (45)	1971-85 + 4 (20)
TOTAL DEPTH	1'-2500' 3 (15)	2501'-5000' 3 (15)	5001'-10,000' 7 (35)	10,001'-20,000'+ 7 (35)
SHOWS PER WELL	No show rpt. 14 (70)	1 show 2 (10)	2 shows 1 (5)	3 shows + 3 (15)
CORES TAKEN PER WELL	No cores rpt. 18 (90)	1 core 2 (10)	2 cores 0 (0)	3 cores + 0 (0)
DST'S PER WELL	No DST rpt. 7 (35)	1 DST 2 (10)	2 DST 3 (15)	3 DST + 8 (40)

55% of all wells drilled reported finding freshwater.

15% of all wells drilled reported finding saltwater.

65% of wells drilled reported formation tops.

0% of the wells were reentered to be worked over or deepened.

10% of the wells were drilled tite.

100% of the wells were D & A.

TOTAL NUMBER OF WELLS SURVEYED = 20

*NOTE: The number in parenthesis denotes percentage.

DIAGRAM B

DRILLING STATISTICS FOR BREWSTER COUNTY, TEXAS

NO. OF WELLS DRILLED BY YEAR	1926-40 0 (0)	1941-55 12 (20)	1956-70 26 (44)	1971-85 + 21 (36)
TOTAL DEPTH	1'-2500' 25 (42)	2501'-5000' 9 (15)	5001'-10,000' 19 (32)	10,001'-20,000'+ 6 (10)
SHOWS PER WELL	No show rpt. 51 (86)	1 show 8 (14)	2 shows 0 (0)	3 shows + 0 (0)
CORES TAKEN PER WELL	No cores rpt. 53 (90)	1 core 2 (3)	2 cores 0 (0)	3 cores + 4 (7)
DST'S PER WELL	No DST rpt. 49 (83)	1 DST 5 (8)	2 DST 3 (5)	3 DST + 2 (4)

29% of all wells drilled reported finding freshwater.

2% of all wells drilled reported finding saltwater.

36% of wells drilled reported formation tops.

5% of the wells were reentered to be worked over or deepened.

19% of the wells were drilled tite.

98% of the wells were D & A.

TOTAL NUMBER OF WELLS SURVEYED = 59

*NOTE: The number in parenthesis denotes percentage.

DIAGRAM C

DRILLING STATISTICS FOR PRESIDIO COUNTY, TEXAS

NO. OF WELLS DRILLED BY YEAR	1926-40 0 (0)	1941-55 10 (28.5)	1956-70 15 (43)	1971-85 + 10 (28.5)
TOTAL DEPTH	1'-2500' 2 (6)	2501'-5000' 4 (11.5)	5001'-10,000' 23 (66)	10,001'-20,000'+ 6 (17)
SHOWS PER WELL	No show rpt. 30 (86)	1 show 4 (11)	2 shows 1 (3)	3 shows + 0 (0)
CORES TAKEN PER WELL	No cores rpt. 28 (80)	1 core 3 (9)	2 cores 0 (0)	3 cores + 4 (6)
DST'S PER WELL	No DST rpt. 26 (74)	1 DST 5 (14)	2 DST 1 (3)	3 DST + 3 (9)

23% of all wells drilled reported finding freshwater.

9% of all wells drilled reported finding saltwater.

31% of wells drilled reported formation tops.

3% of the wells were reentered to be worked over or deepened.

23% of the wells were drilled tite.

100% of the wells were D & A.

TOTAL NUMBER OF WELLS SURVEYED = 35

*NOTE: The number in parenthesis denotes percentage.

followed by testing possible stratigraphic traps. Dejong et al (1985) in a study for Arco, reviewed 1000 miles of CDP seisimic that revealed 65 structural leads of which 45 had significant tests. Usually several wells must first be drilled in an area to delineate stratigraphic plays. Hopefully that day will come for the Trans-Pecos region.

Conclusion -

The probability of finding major reserves (giant oil fields) in the region can be expressed as a fraction of a percent (Dejong et al, 1985). Considering the drilling history of the region, the success of finding commercial reserves can also be expressed as a fraction of a percent though this figure is probably low considering shows. The region still holds potential as attested to by companies still drilling the area today.

Companies are still drawn to: 1) large available or negotiable lease blocks; 2) available seismic and well tie control; 3) accessable locations; 4) a reasonable number of shows in samples recovered and; 5) potential that is not yet truly revealed (sparse drilling). Only the test of time will tell but I surely won't drink all the oil yet to be found in the Trans-Pecos, Texas.

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